A mixed methods analysis of how executive control processes contribute, positively and negatively, to children's creativity

A mixed methods analysis of how executive control processes contribute, positively and negatively, to children's creativity

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A thesis submitted for the degree of Doctor of Philosophy

April 2021

DECLARATION OF ORIGINALITY

I, Cathy Rogers, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, this has been indicated by appropriate author citations.

Abstract

Creativity is one of humanity's most important assets. Training it in children is seen as a crucial component of '21st century skills.' Executive control (EC) comprises a suite of processes shown to improve life chances, from educational attainment to greater health and wealth. This thesis explores the relationship between these two key capabilities, specifically addressing the question of whether training children in EC reduces their creativity.

The first study was a cross-sectional, quantitative investigation of the development of creativity and EC in 45 children aged 5-11 years. Findings showed that while EC measures improved, most creativity measures did not, surprising given expected developmental trajectories for complex cognition. The second, qualitative study involved a subset of the same children and used stimulated recall interviews to elicit descriptions of their mental processes while completing a creativity activity at home. Their verbal reports suggested wide variation in how they deployed EC in their creativity, with differences in the levels of spontaneous (EC independent) and control (EC dependent) processes and in the flexibility to modulate between them. Triangulation of findings showed that greater spontaneity tended to be positively associated with creativity, while extremes of control were negatively associated - the first suggestion that better EC might have negative side effects.

The second set of studies moved from correlation to study causation. A large nested school-based intervention involving 156 children, was designed to train and improve EC in children aged 8-10. Children were randomized by class to the EC group or a matched, active control group and were tested on EC and creativity measures before and after training. The intervention brought about EC improvements in both EC training and control classes, with EC performance improving similarly and significantly in both. The transfer effects to creative performance, also

similar across groups, were mixed; while fluency improved, originality declined. After training to improve EC, children produced more, worse ideas.

The final studies investigated training effects qualitatively, with a subset of children involved in the intervention. This time, they all completed the same activity (as each other and as used in pre and post intervention assessments) to stimulate recall of their thought process while creating. Their qualitative reports formed the basis for defining creative sub types, based on differing cognitive approaches. Triangulation analysis investigated whether the qualitative assessment of the relative degree of control, spontaneity, and flexibility that children deployed in their creativity associated with their performance in quantitative tests. Were there, in short, better or worse ways of 'doing creativity'? Flexibility emerged as a key ingredient to creative success – with more flexible children seeing greater fluency gains after training and less substantial originality losses.

The discussion addresses the question of whether, in our enthusiasm to promote EC training, insufficient consideration has been given to its possible side effects, specifically in demoting original creative thinking. It broadens out to look at the relevance of the current research to education, aligning findings here with an existing conflict between performativity and creativity. Finally, suggestions are made for how to effectively teach children so that their creativity, as well as their EC, can thrive.

Acknowledgements

I would like to thank my supervisors, Michael Thomas and Andy Tolmie, for taking a risk with an academic outsider. Michael, your wise and varied provocations are terrifying in prospect but galvanising in hindsight. Thank you for your eclecticism and openness.

There are many people who have helped me get to grips with new methodological tools. Virginia Eatough, thank you for your generous and enthusiastic guidance on qualitative tools and for giving me the confidence to explore. Nick Midgley, you are a wonderful and insightful friend, I have treasured your thoughts and gentle questioning. Claudia Roebers, thank you for your collaboration and your generosity with both your expertise and materials. The DNL team – Georgie, Gilly, Jo, Lizzy, Olatz, Katie, Matt, Michael, Philip, Hugh, Cosmin, Roberto, Samara, Dom, Roisin, Erica and of course our wise leader Fred – may you keep asking brilliant questions and never letting anything slide. Annette, thank you for this golden legacy. The CEN crew – a powerhouse of shared ideas and practical tips – Su, Annie, Matt, Jess, Katie, Lizzy, Alex, Kathryn – thank you for the generosity and abundance of your thoughts and know-how. Jessica Massonnié, my mind still boggles that someone so young can know so much. You kept me sane through the statistics. You are intelligent, patient, open and curious and best of all you can drum. Sam Wass, fellow creative, thank you for your help in getting me started in all this. I hope I have answered your question, 'But what's wrong with thinking what to do with a paperclip?' James Cordiner, thank you for your incredible assistance with all the data collection, your calmness, your kindness with the children, great book tips and the egg and chip lunches. Madeleine Rogers, you are my favourite designer in the world and your pictures raised everyone's game. Vic Knowland, working with you has been a total pleasure and I hope we will have the chance to collaborate on many more projects - the more unexpected the better. The Budapest gang – Dani, Giacomo, Anne, Teemu, Maggie, Tal, Hansika, Judit, Thomas and the whole crew – thank you for the joyous memories of what feels like another world. Dani, you crazy sister, thank you for such laughs and for teaching me how to text like a teen.

An enormous thank you to all the schools, the heads, the administrative staff, the teachers and above all the children who have taken part in these studies. Your creativity is inspiring, and I hope it continues to flourish. This is for you.

And finally thank you from the bottom of my heart to my family. To my parents for always enthusiastically supporting the twists and turns of my life and career. Jason, thank you for your total and unfailing support and encouragement. You are always there, asking difficult questions, making endless coffee, showing me tech shortcuts and we have been through a lifetime together in the years of this thesis. I'm looking forward to a new life full of space and time with you on the other side. And thank you to my lovely children, mainly for having not the least interest in what on earth I have been up to but knowing that somehow it would be good when it ended.

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AIC	Akaike information criteria
ANOVA	analysis of variance
ATTA	Abbreviated Torrance Tests for Adults
AUT	Alternative uses test
DLPFC	dorsolateral prefrontal cortex
DMN	default mode network
DT	divergent thinking
EC	executive control
ECN	executive control network
fMRI	functional magnetic resonance imaging
GLM	general linear model
IC	inhibitory control
IFG	inferior frontal gyrus
IT	information technology
IRR	inter rater reliability
LMM	linear mixed model
MM	mixed methods
MS	milliseconds

NI	neuroimaging
POV	point of view
RT	reaction time
SD	standard deviation
SEN	special educational need
SR	stimulated recall
TA	think aloud
T/PC	temporal/parietal cortex
TTCT	Torrance Tests of Creative Thinking
VSWM	visuospatial working memory
VWM	verbal working memory
VSR	video stimulated recall
WM	working memory

Chapter 1. General introduction

Chapter overview

The primary goal of this chapter is to present the current evidence regarding the relationship between creativity and executive control. After a brief overview to situate the topic in the broader context of ‘21st century skills’, creativity will be defined and described in terms of its operation and measurement, with attention given to some unique methodological challenges. Relevant models for conceptualising creativity will be outlined and evidence presented regarding its development in children. An introduction to executive control follows, with definitions and descriptions of its operationalisation and an overview of its development to maturity. Evidence regarding interventions designed to improve executive control will also be presented, in anticipation of the intervention study to come.

The relevance of executive control processes to creativity will be discussed at greater length, with evidence presented chiefly from adults and from children where it is available. Evidence comes from a diverse array of brain and behavioural approaches, which implement creativity in a huge variety of ways and this section will lead on to a short description of – and justification for – the methodological approach taken in this thesis.

The last section will set out the main goals and research questions of the thesis, describing how these will attempt to address gaps in our current understanding. Finally, chapter summaries, hinting at the benefits and challenges of a mixed methods approach, will provide an overall outline of the thesis.

21st century skills

"We are currently preparing students for jobs that don't yet exist . . . using technologies that haven't yet been invented . . . to solve problems we don't even know are problems yet." Richard Riley, US Secretary of Education under Clinton (quoted in Trilling & Fadel, 2009, p.3).

Creativity, along with critical thinking, communication, and collaboration, has been cited by the OECD as one of the essential 21st century skills (Schleicher, 2011). Creativity has "like no other mental faculty been omnipotent in transforming human civilizations" (Dietrich & Haider, 2015, p. 897) and responding to a world of accelerating technological, environmental, and demographic change, as well as the new challenges of the pandemic era, means an urgent need for cultivating it. Last year's Durham Commission Report concluded that "All schools, from early years to post-16 education should be better enabled to support the promotion of creativity for all young people" (James et al., 2019). Effectively nurturing creativity first means understanding how it works.

Executive control comprises a set of mental processes that allow us "to think before we act, resist temptations or impulsive reactions, stay focused, reason, problem-solve, flexibly adjust to changed demands or priorities and see things from new and different perspectives" (Diamond & Ling, 2016, p.34). Executive control has been shown to have profound effects on individuals' life outcomes: better control in childhood predicts better academic achievement, and greater wealth, health, and quality of life over the entire life span (Moffitt et al., 2011). The set of skills which make up executive control are also increasingly seen as critical for successful life outcomes (Diamond, 2012, 2013a, 2013b).

How do executive control and creativity relate to one another? Both are seen as desirable, but do they work in harmony? Might improvement in one bring about improvement in the other?

Should we also consider the possibility that they might be antagonistic, for example the narrower focus of greater executive control might reduce awareness of more remote possibilities which might be key to creativity? Might we need to make decisions about which to prioritise? This is more than a theoretical question. Business leaders want to know if it is possible to hire workers who are at once ‘creative and diligent’ (Corgnet et al., 2015, 2016) and there is ongoing debate about whether this ‘best of both worlds’ of high creativity and high control is achievable (Amer et al., 2016; Thompson-Schill et al., 2009). The ambition of this thesis is to set out some answers to these questions.

Creativity

What is it?

Creativity includes activities as diverse as Louise Bourgeois sculpting ‘Maman’, Martha Lane Fox originating Lastminute.com and you thinking how to combine three unlikely ingredients in your fridge in such a way they can be called dinner. Its centrality to human nature (Dietrich & Haider, 2017; Vygotsky, 1930) is such that it is hard to find a discipline which does not study it - behavioural, evolutionary, economic, social, cultural, educational, clinical, computational, historical takes all offering their own perspectives (Runco, 2014). Although there are as many definitions of creativity as there are lenses through which it is viewed, they all share the notion that its most essential defining attribute is the production of something new (Runco & Jaeger, 2012) - also referred to, in psychological research, as novelty, uniqueness or originality (Abraham, 2018). The standard psychological definition includes a second attribute: value (Boden, 2004; Cropley, 2000), variously defined as appropriateness (Dietrich & Kanso, 2010), relevance (Kneller, 1965), fit (Sternberg & Lubart, 1995), usefulness (Runco & Jaeger, 2012) or effectiveness (Basadur et al., 2000). All attempt to capture the notion that, to avoid including as ‘creative’ ideas which are new but might be random or even delusional (Barron, 1955), novelty alone is not enough. Creativity must, whatever the domain of human enterprise, demonstrate some level of originality and be deemed appropriate to the task in hand.

This definition is far from watertight. First, there is no avoiding subjectivity: whether we call it usefulness or appropriateness or value, this factor requires judgement: useful for whom? Appropriate for what? Valuable how? (Amabile, 1982a; Kasof et al., 2007; Kaufman et al., 2008). Notions of what constitutes value also vary across domain (e.g. aesthetic value for painting, commercial value for business innovation (Abraham, 2018)). Second, even the apparently straightforward concept of novelty carries complication; should the novelty of a 5-year-old’s painting be judged in relation to the standard of other 5-year-olds? Children in general? People as a whole? The entirety of art history? Many scholars have proposed (Csikszentmihalyi, 2014; Kaufman & Beghetto, 2009) that novelty must be judged within a particular frame of reference, to fairly measure all levels of creativity from the everyday to the eminent (sometimes referred to as ‘P’ for ‘Psychological’ (new to the person) and ‘H’ for ‘Historical’ (new to humanity); Boden, 1998). Third, are these two factors sufficient? Boden (2004) argues not; she believes a third factor, surprise, should be added, since real creativity involves the unexpected. Conceptualising creative thought in terms of its level of surprise helps us see the levels – from simple association, to exploration to paradigm transformation – at which it might operate (Abraham, 2018; Boden, 2004;). Mackinnon has an even more challenging proposal for a third factor: inclusion of the instantiation of the idea - the production of the creative product (MacKinnon, 1965). While those working in creative fields would likely endorse the sentiment that the enormous creative effort involved in the realisation of an idea should be recognised, from a quantitative psychological perspective, this would render the study of creativity intractable. Instead, psychologists frequently settle for distinguishing creative potential from creative achievement (Collins & Amabile, 1999; Runco, 2004; Runco & Acar, 2012;) to acknowledge the big divide that commonly exists between the ability to produce ideas and the multifarious means needed to realise them (Csikszentmihalyi, 2014).

Models and concepts

Within the psychological field alone, there is an array of approaches, including psychometric (using quantifiable tests), experimental (measuring the effect of changing variables), neurobiological (bringing neuroimaging approaches to bear on the creative processes), biographical (analysing creatives' own accounts of their creativity) and broader sociocultural approaches considering contexts conducive to creativity (Sternberg, 1999). In this section, I will briefly outline some of the key concepts and models which have been applied to the psychological study of creativity, before outlining those aspects I will be focusing on – and the many I will not.

The *Four Ps* model (Rhodes, 1961) is an attempt to systematise different perspectives on creativity to be clearer about the measurement target. The Ps stand for 'Product' (creative output e.g., an idea, a painting, a song), 'Process' (the mental operations, components and stages involved), 'Person' (the creative person, characteristics, personality, temperament, habits) and 'Press' (the broader ecological environment and its role in enhancing or diminishing creativity). All four are an inextricable part of creativity, but each piece of research generally sets its sights on one. This thesis is primarily concerned with process. Our field of interest is the set of mental operations which constitute creative thought.

An early model which remains influential was based on reports of well-known thinkers (most famously the mathematician Poincaré) about their ideational process (Rhodes, 1961; Wallas, 1926), which Wallas characterises in four stages. The first, *preparation*, involves a deliberate investigation of all the relevant aspects of the problem, a sort of readying of the mental soil. Then follows a period of *incubation*, a time of 'voluntary abstention from conscious thought' during which the problem is not being worked on – the thinker is either relaxing or working on something else. The next stage is *illumination*, the 'Aha!' moment, when the solution suddenly appears in the conscious mind as 'that flash of insight that the conscious self can't will and the subliminal self can only welcome' (Popova, 2013) and which represents, often following many unsuccessful attempts, 'a successful train of association' (Wallas, 1926). The final *verification* stage is the mirror of preparation, a deliberate and conscious testing of the idea's validity, a stage demanding 'discipline, attention, will, and consequently, conscious work' (Wallas, 1926). The model is characterised by a recursive shuttling between conscious and unconscious thought processes along unpredictable timelines and with success not easily fitting into a 'problem and solution' scheme (Rothenberg & Hausman, 1976), making lab verification almost impossible and leading some to challenge the model (Lubart, 2001) for its lack of empirical evidence. Nonetheless, aspects of the various stages have been widely studied (e.g. insight (Bowden et al., 2005; Jung-Beeman et al., 2004; Kounios & Beeman, 2015; Kounios et al., 2006;)) and it is included here as a first suggestion of the complexity of the role that executive control might play in different stages of the process.

Guilford, seen by many as the founding father of contemporary creativity research (Sternberg & Grigorenko, 2001) following his plea to the American Psychological Association to get serious about creativity (Guilford, 1950), offered one of the first conceptualisations of a 'dual process' model of creativity (Guilford, 1950, 1956; Runco 2014). His ‘Structure of Intellect Model’ was highly specified, with as many as 180 separate possible mental tasks outlined (Guilford, 1956), but the main aspect which has endured was his differentiation of divergent from convergent thinking processes. *Divergent thinking processes* are characterised by being open and exploratory and generating multiple possible ideas. Several researchers align them with associative processes, in which items in memory and from the senses are combined to bring about novel combinations (Gabora, 2010; Martindale, 1999; Sowden et al., 2015a). *Convergent thinking processes*, by contrast, involve production of a single solution during creative problem solving and are more concerned with evaluation and refinement. As such they are generally regarded as being more analytical in nature (Guilford, 1956, 1967a; Sowden et al., 2015a). The main use of Guilford’s model has been in its direct application to the creation of a set of tests, primarily of divergent thinking, which remain the most commonly used tests for ‘creativity’ more than seventy years later (Guilford, 1966, 1978; Runco, 2014).

Dual process theories, which characterise the brain as having two distinct information processing systems that drive a common behaviour, are common in psychology and neuroscience (Abraham, 2018; Dietrich 2018). One system (often called Type 1) is automatic, quick and unconscious – in folk terms, the equivalent of our instinct or gut reaction, while the second (Type 2) is slow, effortful, analytic and controlled – more linked to, again in folk terms, our rational side (Evans, 2008, 2010; Sowden et al., 2015a; Stanovich, 1999). More specifically, Type 2 but not Type 1 processes are held to require working memory (Evans & Stanovich, 2013).

The idea of this dual set of processes has been extended to the study of creativity, with several models adapting and applying it (Abraham, 2014; Beaty et al., 2014; Dietrich, 2018; Finke, 1996; Limb & Braun, 2008; Ward et al., 1997). Ward and Finke’s *Geneplore* model outlines proposed operations and stages involved in creative cognition (Finke, 1996; Finke et al., 1992; Ward et al., 1997) in a way that does not explicitly evoke the dual systems approach but has clear links to it (Sowden et al., 2015a). The Geneplore (‘Gen’ for ‘*Generate*’, ‘Plore’ for ‘*Explore*’) describes a first generative phase in which ‘preinventive structures’, such as creative mental images, are produced, either by spontaneous or intentional means. In the exploratory phase, these structures are manipulated and explored, again by means which are either intentional or which ‘occur outside one’s awareness or conscious control’ (Finke et al., 1992), and the preinventive structures are modified or replaced. This cycle can be repeated indefinitely until a solution is reached, with additional constraints imposed at any stage of the generative or exploratory phases.

A key aspect of the Geneplore model is that it resists the common temptation (Dietrich, 2015) to straightforwardly yoke generation to associative ‘Type 1’ and exploration to analytic ‘Type 2’ processes. Top down, goal-directed processes as well as bottom up, exploratory processes can each contribute to both generation and exploration (Finke et al., 1992; Finke, 1996; Ward et al., 1997). While this is a strength in terms of resisting over-simplification, it is potentially also a weakness in that, if the different stages are approachable by almost any kind of thought process, how does the distinction aid our understanding of the mechanics?

A more recent and less generalised dual process theory, suggested by Nijstad and colleagues (Baas et al., 2013; De Dreu et al., 2008; Nijstad et al., 2010), proposes that there are two distinct means to achieving creative ends, one via a *flexibility pathway* in which a volume of different categories of candidate ideas is produced, and another via a *persistence pathway* involving exploration of very few categories in greater depth. Psychological states and traits can, they argue, influence creativity via their influence on these pathways, with activation of positive mood states enhancing creativity through stimulating flexibility, and activation of negative mood states enhancing it through stimulating the persistence pathway (Nijstad et al., 2010). A limitation of the model is that, as the authors say, it "applies to situations in which at least some (conscious) attention is directed at a task that requires creativity (i.e., it applies to deliberative rather than automatic processes) … not to situations in which creativity occurs 'spontaneously' without intentional effort" (Nijstad et al., 2010, p.43), raising questions about its ecological validity (Sowden et al., 2015a).

Several researchers have drawn upon an evolutionary analogy in conceptualising creative thinking, since creativity's generate / investigate iterative process maps well to evolutionary theory's variation / selection (Campbell, 1960; Dietrich, 2015; Simonton, 1999). The analogy pushes researchers to think about a unique aspect of creative thought: its operation within an unknown problem space, where reliable predictions cannot be made (hence the description of it as 'blind' in Campbell's (1960) Blind Variation and Selective Retention (BVSR) model) - though perhaps not completely blind, since a key advantage of cultural over biological evolution is the human brain's ability to run mental simulations. "An arch with a keystone is the canonical example of an interlocking design that must leap over non-adaptive, intermediate forms… biological evolution cannot do that" (Dietrich, 2015, p.131). Simonton, whose Darwinian theory of creativity (Simonton, 1999, 2010b) is itself an evolution of Campbell's BVSR model (Campbell, 1960), has demonstrated, through studying historical records of eminent creatives (Edison, Tesla and others) that, as would be predicted by an evolutionary model, creativity results in a lot of waste. Edison held no less than 1,093 patents. To put it another way, "quality is a probabilistic function of quantity" (Dietrich, 2015, p.104).

One of the problems of the evolutionary take on creativity has been that it has been "nearly universally ignored in setting up empirical protocols" (Dietrich & Haider, 2017, p.3), meaning that it remains largely theoretical (in a review, Simonton points out that researchers "have been largely content to marshal past empirical research on the theory's behalf rather than design new empirical tests of particular predictions" (2010, p.173)). Again though, the element salient to our research here is the idea that successfully achieving creativity requires bringing both controlled (chiefly the *selection* aspect) and uncontrolled (chiefly the *variation*) processes to bear.

Dietrich has proposed a model of creative thinking which is itself quite creative, in amalgamating the 'best of the best' from other creativity models and from cognitive neuroscience models more broadly (Dietrich, 2015, 2019; Dietrich & Haider, 2015, 2017). He combines three main elements: the evolutionary framework described above, the prediction framework (Wolpert et al., 1995, 2003) that takes predictive representations to be a central integrating principle of cognition, and the dual system view that there are two distinct systems for knowledge representations, one explicit and one implicit (Dienes & Perner, 1999; Reber, 1993). Within this framework, creativity proceeds via three possible routes:

- the deliberate mode (a top-down approach in which thought trials are run through representations of predicted goals (RPGs) in a recursive variation / selection cycle to tackle explicit goals)
- the spontaneous mode (essentially similar but involving much less top-down control and likely to arise through task set inertia, (which might be described as a form of mind-wandering) (Allport & Wylie, 2000; Wylie & Allport, 2000) making it on the one hand less efficient and on the other more likely, being less directional, to chance upon more remote and paradigm-shifting associations; this mode is at work during an idea's incubation phase

- ‘flow’ (Csikszentmihalyi et al., 1990), a fully implicit system brought about through transient hypofrontality (i.e., a state of reduced executive control) in which perception and action meld and variation / selection trials are blind since no prediction mechanism is at work (Dietrich, 2015; Dietrich & Haider, 2017).

Dietrich is the creativity field’s resident iconoclast (“We know next to nothing about how brains generate creative ideas”, the field is “theoretically incoherent” etc.) (Dietrich & Haider, 2017, p.1; Dietrich & Kanso, 2010) and his view that all creativity research to date has been a waste of time is extreme. However, his notion that in considering creative thought somehow ‘other’, we have ignored important evidence is credible - and his framework offers the benefit of being grounded in many existing cognitive neuroscience theories for which there is already much empirical evidence (e.g., Allport et al., 1994; Dehaene & Changeux, 2011; Raichle et al., 2001; Wolpert et al., 2003). Its major limitations, through protesting too much that creativity should not be seen as ‘other’, are that it fails to show what (if anything) is unique about creativity and does not offer up testable hypotheses which could render it falsifiable (Abraham, 2018).

The purpose of outlining these theoretical models and frameworks, is to provide a context within which to situate the current work – both the quantitative work, which will be driven by the relatively bounded data derived from lab tests of creativity, and the qualitative work in which data involving a wider range of concepts and approaches might potentially be relevant. More specifically, this theoretical section has attempted to demonstrate that the question central to this thesis – how executive control processes contribute to creativity – also lies implicitly within most of the theories. Although direct mappings are over simplistic (e.g., seeing evaluation exclusively as a process under executive control or generation as a process involving only free association and thus outside of executive control), it would be disingenuous to see no mapping at all. Many propose that apparent dichotomies (e.g., divergent/convergent thinking) are better seen as continua (Eysenck, 2003; Runco, 2014), an idea going back to Mednick (1962) who characterised a continuum of ‘associative hierarchies.’ In this view, more creative people have flatter hierarchies: when a concept is activated for them, it activates many other concepts weakly, rather than few concepts strongly, as it does for less creative people. With this theoretical complexity directly confronted, we now turn to some specifics about how we might measure creativity in practice.

How is it measured?

“While the field of creativity has managed to find agreement on the definition of creativity, researchers are less clear on how creativity should be operationalised and measured.” (Reiter-Palmon et al., 2019 p.144)

There are as many ways of measuring creativity as there are perspectives on it – from very broad approaches, such as analysing environments conducive to creativity, to very narrow ones, such as neuroimaging trials to examine the brain activity involved in insight. Our focus here will be on methods used in psychology and neuroscience to better understand the creative process. There are some unique practical problems (Abraham, 2018; Dietrich & Kanso, 2010; Sawyer, 2011) in the neuroscientific study of creativity: for functional magnetic resonance imaging (fMRI), the constriction of movement in the scanner limits many types of domain-specific creativity experiment; responses in creativity paradigms involve generation of ideas rather than a simple reaction to a stimulus, meaning more time is needed, meaning in turn fewer trials and less power to detect brain activity (Liu et al., 2001). Repeated trials cause problems in that they must be similar enough to allow comparison and averaging, while being different enough still to be testing creativity, which is partly defined by novelty. A similar issue arises with finding appropriate control tasks for the many, often only loosely specified creativity tasks available (Abraham, 2018; Dietrich, 2007b, 2015). And this is all in addition to the capricious nature of creativity itself. “Clearly one cannot simply take a volunteer, shove him/her into the nearest brain scanner, and tell /her: Now please be creative!” (Dietrich & Kanso, 2010, p.822).

There are essentially two main toolsets for studying the creative process. First and most common are the divergent thinking tests, still the mainstay of creativity research. Divergent thinking is the ability to generate multiple answers to a given stimulus (Guilford, 1967b), an ability which, though certainly not the whole story of creativity, is a component (Guilford, 1966; Reiter-Palmon et al., 2019). By far the most frequently used are the Alternative Uses Test (AUT) (Guilford et al., 1978), in which participants are asked to generate multiple interesting, unusual alternative uses for an everyday household item such as a brick or a newspaper, and the Torrance Tests of Creative Thinking (TTCT) (Torrance, 1966, 1972, 1974), an array of tests designed to assess fluency, flexibility, originality, elaboration and a range of specific creative qualities (such as humour, expressiveness) in both verbal and figural domains. Wallach and Kogan (1965) emphasised the importance of carrying out tests in a game-like atmosphere with the avoidance of strict time limits.

Second are convergent thinking tasks, of which the most widely used is the Remote Associates Task (RAT) (Mednick, 1962) in which participants are given a list of word triads (e.g., illness, bus, computer) and must try to find a fourth word associated with each of them (here, the answer is ‘terminal’). Convergent thinking tasks also include specific problem-solving tasks such as Duncker’s candle task (Duncker & Lees, 1945) or tasks involving rearranging matchsticks according to rules which are apparently simple but practically perplexing, usually requiring mini ‘eureka’ moments to solve (Knoblich et al., 1999).

It is worth mentioning that these longstanding ‘tests for creativity’ were mostly not designed as such. Guilford’s tests were one of many designed to explore and map his ‘structure of intellect’ model (Guilford, 1956) and Torrance’s interest was in trying to understand and nurture specific qualities which allow people to express their creativity (Kim, 2006; Torrance, 1966, 1974;) rather than to test it. Mednick did wish to explore his notion that individual differences in creativity arose through differences in associational hierarchies, but in his test, the creativity involved is assumed rather than deduced (a fact he was himself aware of) and solutions can also be produced by brute force, non-creative means (Mednick, 1962).

For the quantitative studies carried out in this thesis (as well as the final qualitative study), divergent thinking tests will be used. The tests mentioned (AUT and TTCT) have been used in many contexts with many different groups, including children, the tests are straightforward and speedy to administer, and the wealth of published studies allows for comparison. They have been widely examined in terms of reliability and validity (Kim, 2006; Silvia et al., 2008). The TTCT figural tests, which have been normed several times on large samples (Kim, 2006, 2011) have high predictive validity over a wide range of ages (Cropley, 2000) e.g., in one analysis, they accounted for half the variance of scores in creative achievement and creative participation several years later (Plucker, 1999), test-retest reliability is reasonably high (between .5 and .93) (Treffinger, 1985) and when tests are used with children, they have been shown to be a significantly stronger predictor of adult creative achievement than other cognitive measures such as IQ, suggesting some level of discriminant validity (Plucker, 1999). The evidence is not all positive. Simonton (2003b) found that scores on creativity tests correlated highly with IQ (i.e., low divergent validity) but poorly with each other (i.e., low convergent validity) as well as showing poor predictive validity of real-world creative achievement (Silvia et al., 2008), a finding in conflict with other analyses, and one that suggests findings might vary a great deal, depending on the nature of the outcome metric (e.g., the wide range of meanings of 'creative achievement'; Carson et al., 2005). The problems with construct validity are considerable (Plucker, 1999, 2017; Abraham, 2018; Silvia et al., 2008). To understand how and why, we need to go into some more detail about how these tests are executed and scored.

The first striking point, particularly given the effort to reach accord that creativity should be defined in terms of originality and value, is that divergent thinking tests are not scored according to these criteria (Reiter-Palmon et al., 2019; Runco, 2008; Runco & Charles, 1993). Instead, tests produce an array of sub measures, none of which contain the word 'value', which is at best implied, and within which even 'originality' is ambiguous. The reason for this apparent illogic is this: researchers almost unanimously agree in theory that 'divergent thinking' and 'creativity' are not synonymous (Plucker & Renzulli, 1999; Dietrich & Kanso, 2010; Nusbaum et al., 2014) so it is theoretically justified to score divergent thinking tests according to their own criteria (Reiter-Palmon et al., 2019; Plucker et al., 2014). In practice, however, most creativity research *does* use divergent thinking as a proxy for creativity – so researchers are left in something of a logical bind: either score the tests according to the definition of the 'master concept' of creativity, implying that divergent thinking does tell the whole story, or score them according to their own rule set and be left with a gap between findings about divergent thinking abilities and creativity. Despite many efforts over the years to improve the rigour and coherence of measures used in creativity research (Plucker et al., 2004; Silvia et al., 2008; Lubart & Besancon, 2017; Forthmann et al., 2018, 2020a, 2020b) there is still some way to go (Puryear & Lamb, 2020).

The AUT is typically scored, as Guilford outlined (Guilford, 1967), on the dimensions of fluency – a simple sum of responses, flexibility – the number of different categories of response, elaboration – a measure of detail in responses (used relatively rarely; Reiter-Palmon et al., 2019), and originality. Originality is the most complex sub measure for two distinct but related reasons. First, it can be scored either according to the 'frequency method', a measure of statistical rarity within the sample (or a separate comparable sample) or the 'rater method', in which responses are scored by a group of independent raters who give each response a scaled score (typically 1 to 5), according to instructions which are often unspecified in publications. The frequency method is often seen as a more objective measure (Reiter-Palmon et al., 2019; Runco, 2008) but even here subjective decisions are involved, for example in judging response similarity (is using a water bottle 'to carry milk' the same as 'to carry orange juice' or 'to carry a potion'? (Plucker et al., 2014)). The rater method is by definition subjective on the part of the raters (Cseh & Jeffries, 2019; Reiter-Palmon et al., 2019) but can also be affected by researcher guidance; for example, raters might be guided to score on unusualness, or cleverness, or imaginativeness, or to include their sense of the feasibility or appropriateness of an idea, thus also incorporating a value dimension.

The second problem is how to aggregate scores to calculate a participant's overall originality from their individual response scores. Again, there are several methods. Simple summing of response scores means high contamination with fluency scores (Plucker et al., 2011), while a ratio score (dividing summed originality by fluency) can have the opposite effect of penalising high fluency (Forthmann et al., 2018; Plucker et al., 2011), leading others to propose a range of workarounds such as 'top two' scoring (Silvia et al., 2008) or 'ideational pool' scoring (Forthmann et al., 2020a, 2020b; Plucker et al., 2014). No method is without its problems. First, there is reason to believe that scores represent different mental operations (Vartanian et al., 2020), as evidenced by variable correlations with IQ and EC measures (Benedek et al., 2012, 2014a). Second, the choice of aggregation method might reflect researchers' underlying theories about how creativity is implemented (Forthmann et al., 2020a, 2020b), e.g., whether originality is achieved through a 'scattergun' approach of exploring many possible idea candidates - in which case correlation with fluency would likely be high, or by a strict, exclusionary 'honing' approach, where correlation would be low. This makes it vital that researchers are explicit about their theoretical position.

If issues of scoring are important, so too are issues of instruction. One of the most observed findings in creativity research using divergent thinking tests is the so-called 'Be creative' effect which shows that if participants are instructed to emphasise quality, the originality of their responses is boosted (Chen et al., 2005; Silvia et al., 2008). The effect has even been used as a paradigm for exploring executive involvement in ideation (Nusbaum et al., 2014). These experiments will be discussed in the following section: for now, the salient point is that task instruction detail matters. A second highly replicated finding is the 'Serial order effect' which shows that responses to divergent thinking tests diminish in quantity (fluency) but improve in quality (originality) over time (Beaty & Silvia, 2012; Wang et al., 2017). Again, different interpretations of this finding will be explored later, but the important point from a methodological point of view, is that the amount of time given for tests can also profoundly affect results (Beaty & Silvia, 2012; Plucker et al., 2006).

This section has shown that there are a host of issues of test execution and scoring which can drastically alter findings. As a final illustration of this, a recent study looked at the effects of different scoring approaches on neuroimaging findings. Vartanian and colleagues (Vartanian et al., 2020) used voxel-based morphometry (VBM) to determine the correlation between regional grey matter volume (GMV) variation and seven different scores from the AUT. They compared the four traditional sub-scores (fluency, flexibility, originality, and elaboration) with a subjective 'snapshot' measure (Silvia et al., 2008) in which raters assessed each participant's output as a whole, and a third approach, using the definitional terms of novelty and usefulness (Kaufman & Sternberg, 2019). Results from multiple regression analysis revealed that only novelty and usefulness showed any significant correlation – a negative one, with the left inferior temporal gyrus, while the other five measures showed none. This was despite the fact that the measures themselves were, with the exception of elaboration, significantly correlated. Such results might reasonably cause despair ("To most scientists, the prospect of studying creativity in the lab must seem like trying to nail jelly to the wall" (Dietrich, 2007b, p.1) but certainly show the need to tread extremely carefully when it comes to the details of even the field's most commonly used tests.

A note on the approach taken here

Given the vast array of creativity components, it might be helpful to be explicit about the many that are not within the scope of this thesis: insight (Kounios & Beeman, 2015), imagery (Finke, 1996), problem solving (Duncker & Lees, 1945), the role of the imagination (Singer, 1999), convergent thinking tasks (Bowden & Jung-Beeman, 2003), analogy and metaphor (Hofstadter & Sander, 2013), flow (Csikszentmihalyi et al., 1990) and conceptual expansion (Abraham, 2012). Instead, the starting point for the current research will be the divergent thinking tests discussed in some detail above. By using familiar tests but applying new approaches - particularly the sort of detailed, first person, chronometric approach that qualitative interviewing allows – the goal is to provide new insights to the cognitive mechanisms involved. The approach itself sets out to be creative – achieving novelty through applying new methods, and value through relating the current work to the existing literature.

How does it typically develop?

The creative process is, according to Vygotsky (1930), ‘already manifest in earliest childhood’ and easily seen in children’s play; when a toddler is riding a toy horse pretending to be a princess, she is not merely reproducing experience but creatively reworking it, demonstrating the ‘double, mutual dependence between imagination and experience’ which, for him, is creativity’s essence. Researchers have recently developed tools to test the divergent thinking abilities of children as young as 1 (Bijvoet-van den Berg & Hoicka, 2014; Hoicka et al., 2016, 2017). The Unusual Box Test is a brightly coloured wooden box with many moving parts and objects within. Children are shown the box and then left to explore it; their movements subsequently scored for fluency (number) and originality (statistical rarity within the sample). The box has shown good test-retest reliability as well as high correlations (around 0.6 depending on sub scores) with other divergent thinking tests such as Torrance’s Thinking Creatively in Action and Movement (Zachopoulou et al., 2009) in which children have to, for example ‘move across the room in as many ways as possible’, and the Instances test in which they must cite instances of, for example, ‘as many things as they can think of which are round’ (Wallach & Kogan, 1965). The chief advantage of the box is its potential for use with very young children (the other tests mentioned are typically used for children over 3).

There is much evidence that creativity can be improved, using techniques that promote creativity-fostering environments (Amabile, 1983; Hennessey & Amabile, 1988; Sternberg & Lubart, 1995), by specific training tactics, such as the use of analogies (Root-Bernstein & Root-Bernstein, 1999), heuristics to enhance divergent thinking (Runco et al., 2005) or strategies to aid problem-solving (Osburn & Mumford, 2006). This evidence, which applies to both children and adults (Runco, 2014; Russ & Fiorelli, 2010), will be dealt with more fully in the final chapter when we consider education through the *21st century skills* lens. For now, it is mentioned chiefly to show that creativity is highly malleable, so much so that researchers are confident to claim that "Everyone has the potential to be creative". However, "not everyone fulfils that potential" (Runco, 2014, p.39). This begs the question of what processes convert (or fail to), creative potential into actual creativity. There are two complexities to consider in answering this. The first is that creativity is a reflection not just of cognition but of motivation, personality, temperament, mood, domain, emotion and more (Amabile, 2018; Runco, 2014), so identifying the sources of success or failure in achieving creativity means scouring a very wide field. The second is the difficulty of differentiating training from developmental effects (Jolles & Crone, 2012), a theoretical issue that, as we shall see, will become of great practical concern in the training study in Chapter 5. The complexity here lies essentially in the fact that development itself is complex: on the one hand, the high level of neural plasticity during development make childhood potentially ripe for training interventions, but on the other hand, there might be constraints determined by the specific state of structural and functional brain development, which might limit the success of training (Jolles & Crone, 2012). To date there remains no comprehensive theory of the development of creativity (Alfonso-Benlliure & Santos, 2016). In part, progress has been vexed by methodological issues such as the majority of studies relying on cross-sectional rather than longitudinal designs (Kim, 2011), tests being highly specific (such that when studies deploy multiple tasks over time to the same children, they find distinct developmental trajectories for each task; Barbot et al., 2016; Claxton et al., 2005), the test-retest issues which plague many of the tests used in creativity research (Barbot et al., 2016, 2019b), the negative effects caused by strict time constraints and test-like settings being felt particularly acutely by children (Runco, 2016), and questions pertaining to domain generality/specificity (would the child prodigy violinist or artist be moved to think of alternate uses for a brick?). It is little wonder that creative development is characterised by a series of ‘lumps and bumps’ (Barbot et al., 2016; Runco, 2016; Sternberg & Lubart, 1995), with discrepant levels of recovery from downturns. One of the best documented, though consistently controversial, downturn (Claxton et al., 2005; Said-Metwaly et al., 2020; Sak & Maker, 2006), is the ‘fourth grade slump’ (i.e., children aged 9 and 10), first identified by Torrance (1968). Contradictory findings regarding the slump might in part be explained by differences in the tests used: a recent meta-analysis looking specifically at divergent thinking, which suggested an overall upward developmental trend with some discontinuities, found that performance improvements were moderated by ‘DT test, task content domain, intellectual giftedness, and country of study’ (Said-Metwaly et al., 2020). Slumps, or downturns are often attributed to children’s improved reasoning abilities, which emphasise convention and logic over creativity and imagination. According to Kohlberg (1987), young children are preconventional - they do not yet understand the rules they are expected to abide by, but by middle childhood most have entered a conventional stage, sometimes giving great weight to normative behaviours. The link with creativity – or the severing of it - is clear, since originality is essentially defined by its deviation from norms (Runco & Jaeger, 2012).

There are significant individual differences in both the timing of and recovery from slumps. One possible cause for this is asynchronicity i.e., differences in the timing of the development of other mental processes. Environmental influences have also been investigated; for example, cultural factors seem to be play a role (e.g., slumps seem to start younger in China than the USA; Chan et al., 2001; Yi et al., 2013), as do family environments, with authoritarian parenting being associated with deeper, more persistent slumps (Dacey, 1998, 1999; Fearon et al., 2013).

Developmental adversity can sometimes, paradoxically, foster creativity through pushing people outside the realm of normality (Makin, 2016).

Recently, attempts have been made to understand the neural factors underlying these fluctuations (Saggar et al., 2019). Using a longitudinal, cohort-sequential design, Saggar and team assessed 48 3rd and 4th graders using lab tests of creativity, IQ, and executive control (EC), temperament and behaviour questionnaires, and Functional Near-Infrared Spectroscopy (fNIRS) while the children performed creative (and control) drawing tasks. They found three distinct developmental trajectories, one in which children slumped then bumped, another in which they bumped then slumped and a final group who were flat and then bumped. They relate the trajectories to externalising behaviours (e.g., rule-breaking, aggression), which were positively associated with creativity and found that creativity improvements were also related to increased functional segregation of the right lateral prefrontal cortex, the brain's seat of executive control. These two findings appear somewhat contradictory, and the researchers note that other behavioural markers such as response inhibition showed no association with externalising behaviours. The evidence base rested on a single overall measure for creativity (specified only as the 'mean' from the Torrance figural tasks, a set usually resulting in at least 6 different sub measures) making a full interpretation and unpicking of their findings - even straightforward points such as fluency / originality distinctions – difficult. The authors themselves note that "the common cognitive and neural mechanisms of rule-breaking and creativity remain unclear" (p. 100). Some children appear not to recover from their slumps, continuing to show declines in creativity over the school years (Kim, 2006; Lubart & Lautrey, 1995), with some suggesting that it is the school environment itself which constrains creative thought (Robinson, 2011a, 2011b; Doron, 2016; Baer, 2016; Beghetto & Kaufman, 2014; Runco et al., 2017). Other studies have found the opposite - that creativity scores increase with age (Besancon & Lubart, 2008; Mouchiroud & Lubart, 2001, 2002; Smith & Carlsson, 1983, 1985), with the explanation often rooted in the greater experience that older children clearly have. Since some see creativity as “the capacity to construct original meaning from interpretations of experience” (Runco, 2008, quoted in Runco, 2016; also, Vygotsky, 2004), having more experience to draw upon is clearly advantageous. A difficulty with interpreting often conflicting evidence arises from the plethora of creativity sub measures; researchers vary in which they emphasise according to their theoretical position, the choice of test and their particular research interest. For example, one sub measure used in both figural and verbal DT tests is ‘elaboration’, largely a measure of detail in responses. It is likely to show age-related improvement as children have more sophisticated language and greater dexterity. (Kim, 2011). Fluency, too, might improve with age in time limited tests, since older children can think, write, and draw more quickly. Originality, by contrast – though depending on how it is scored – might be less clearly aligned with age: while greater experience might admit more novel ideas, reason’s increasing ascendency over imagination might push the opposite way (Vygotsky, 1930). The issue of which sub measure best represents creativity will be confronted, theoretically and practically. in the cross-sectional study in Chapter 2.

One consistent finding in a mosaic of data is that divergent thinking ability and evaluative ability do not follow the same developmental paths. While research suggests divergent thought has a turbulent trajectory, there is relative consensus that evaluation improves with age, as children develop a better understanding of what is valued by others (Runco & Acar, 2012) and put more emphasis on appropriateness (Charles & Runco, 2001). This improvement, involving both skill at appraising feasibility and better theory of mind understanding, is likely to be buttressed by the development of executive control (Carlson et al., 2002, 2004), and is another important clue for the current work.

Executive control

What is it?

Executive control, also known as ‘executive functions’ (Diamond, 2013; Kerr & Zelazo, 2004) and ‘cognitive control’ (Miller & Cohen, 2001) is the ‘manipulation and prioritization of information in the brain to achieve desired goals’ (Johnson & Haan, 2015). The term refers to a family of top-down, effortful processes which are required when there is the need to pay attention, hold information in mind, adapt and plan ahead (Davidson et al., 2006) rather than rely on intuition or instinct (Diamond, 2013).

The structure of executive control was first conceived as a single construct (Sala et al., 1998) but the broadly accepted current view is that it comprises a set of interrelated and interdependent processes that are somewhat dissociable (Kerr & Zelazo, 2004). And although some point to ongoing debate as to precisely what those separable processes are (making EC impossible ‘to define in a way that entirely satisfies any two colleagues’ (Astle & Scerif, 2008)) there is some consensus that achieving our goals demands three core capabilities: storing and using information in working memory (Baddeley, 1996), flexibly switching between tasks, and inhibitory control - both in terms of control of cognitive interference and self-control (Diamond, 2013). Miyake et al.’s influential 2000 study, which involved extensive testing on a host of EC tasks within this triad, found both unity and diversity: confirmatory factor analysis showed that ‘updating’ (working memory), ‘shifting’ (flexibility) and ‘inhibition’ were ‘moderately correlated but clearly separable' (Miyake et al., 2000). The figure below (Fig. 1.1, from Diamond, 2013) suggests a model for how these core processes interact and form the basis for higher level decision making, mediated by the prefrontal cortex (Kerr & Zelazo, 2004).

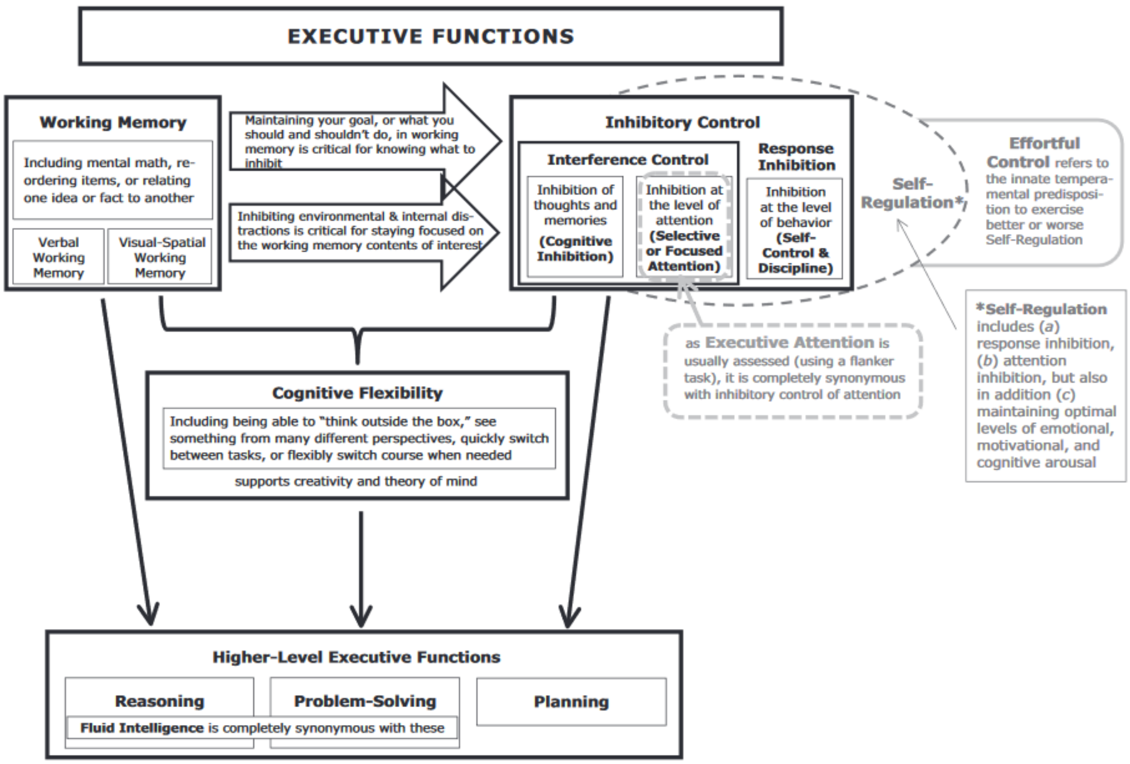


Fig. 1. 1 From Diamond, 2013. Executive functions and related terms

EC is not detached from other brain functions but rather is inextricably linked to emotions (Immordino-Yang, 2015; Schmeichel, 2007), motivation (Pessoa, 2009), stress levels (Derakshan & Eysenck, 2009) as well as to broader biological factors such as hormones, nutrition, rest, and exercise. A common distinction is made between 'cold' and 'hot' EC (Zimmerman et al., 2016); cold control, deploying clinically efficient executive processes such as planning and inhibition, is associated with the dorsolateral prefrontal cortical regions while hot control, which supports behaviours which demand emotional regulation or awareness and empathy, is supported by regions in the ventromedial and orbito-frontal cortex (Chan et al., 2008). The evidence suggests that, neurologically and behaviourally, there is a continuum from colder to hotter skills, with the balance led by the motivational and emotional weight of the task at hand (Zelazo & Carlson, 20112; Zelazo et al., 2008, 2010).

It is beyond the scope of this thesis to expand fully on the brain basis for EC processes, but it is relevant to appreciate the breadth, complexity, and dynamism of what is meant when we talk about executive control. It is a description of ends more than a detailed description of means, essentially 'an umbrella concept, encompassing a variety of, potentially disparate, mechanisms' (Astle & Scerif, 2008), something that will become highly relevant when we try to understand its form as enacted and described by young children.

Why is it important?

Understanding executive control helps us see "how children, who often 'act without thinking', develop into mature, responsible adults, able to plan and control their actions" (Mulder & Cragg, 2014). It is apparent why so much attention has been placed on this compendium of skills, since the benefits it sustains are legion and far-reaching - from school achievement (Gathercole, 2004b) to physical and mental health (Crescioni et al., 2011; Diamond, 2013), job success (Bailey, 2007) and quality of life (Brown & Landgraf, 2010).

The context of most relevance to the current work is schooling. Here we also find evidence of the wide-ranging benefits of good EC. It plays a central role in school readiness (as measured by emergent literacy, phonological awareness, orthographic knowledge, and emergent mathematic knowledge) in pre-schoolers (Shaul & Schwartz, 2014), in mathematics proficiency (Cragg & Gilmore, 2014) and in reading ability (Cartwright, 2012). EC has been shown to be a strong predictor of academic achievement in English, Maths and Science (e.g., WM accounted for between 16 and 20% of variance in literacy and numeracy scores; Alloway & Alloway, 2010), and has been shown to better predict overall success throughout the school years than IQ (e.g., a composite self-control measure accounted for twice as much of the variance in Final Grade Point Average scores as IQ; Duckworth & Seligman, 2005).

How is it measured?

There are many tests available to assess executive control by digital or analogue means. Some of the most commonly used are the Wisconsin card sort, various versions of Stroop, anti-saccade tasks, go/no go, digit span and backwards digit span tasks, keep track tasks, Navon global/local tasks, Simon tasks, Towers of Hanoi/London, Flanker, random number generation and various dual tasks combining elements to be completed simultaneously or alternately (Miyake et al., 2000). Many are used as standard tests for single EC components (e.g., Stroop for inhibitory control) but the issue of task impurity (i.e., the fact that any executive task implicates additional cognitive processes as well as the test target itself) is widely recognised (Cepeda et al., 2001; Luna et al., 2004; Miyake et al., 2000). For example, in the Wisconsin card sort task, participants must sort cards according to rules of colour, shape and number. The changing rules necessitate frequent ‘switching’ and the test is generally taken as a measure of switching flexibility (Greve et al., 2005; Nyhus & Barceló, 2009; Miyake et al., 2000). But when the task instruction changes from ‘sort by shape’ to ‘sort by colour’, is the key cognitive work successful administration of the rule change (shifting), blocking the prior rule (inhibitory control) or keeping the relevant information in mind (working memory)? Fractionating the relevant cognitive processes is difficult (Cepeda et al., 2001), a complexity compounded by EC’s involvement in the regulation of other cognitive processes such as executing verbal or motor responses (Ven et al., 2013).

Another critique levelled at EC tests focuses on doubt surrounding their ecological validity – the extent to which lab findings reflect the real world (Wallisch et al., 2018). Researchers, cite, for example, children with severe behavioural problems at home or school who behave impeccably in the lab (Anderson, 2002). EC measures are also often inconsistent in the same individual at different time points (Anderson, 2002) and the specifics of the interplay between context and performance is not well understood (Wallisch et al., 2018). A conceptual difficulty with EC tests lies in the fact that task success might be achieved by different neural pathways at different ages (Astle & Scerif, 2007; Karmiloff-Smith, 1998), clearly a problem if the aim is to understand the processes embedded in what we call EC and not just their behavioural output.

How does it typically develop?

Executive processes emerge in infancy and develop throughout childhood into early adulthood (Anderson, 2002; Diamond, 2013); recent research has highlighted their protracted continued development throughout adolescence (Blakemore, 2006; Davidson et al., 2006; Luna et al., 2004). The constituent EC components differ in their developmental trajectories, supporting arguments for their separability (Huizinga et al., 2006; Lee et al., 2013) though with considerable unity – in Miyake and colleagues' latent variable analysis, correlations between the three factors of updating, shifting and inhibition were moderately high, estimated to range between .42 and .63 (Miyake et al., 2000). Some studies support the three-factor structure (e.g., Rose et al., 2011) while others suggest that the structure changes with age (Lee et al., 2013). An emerging picture is one of undifferentiated EC in the preschool years (Lee et al., 2013; Wiebe et al., 2008) giving way to a two factor structure (comprised either of working memory and shifting (Huizinga et al., 2006) or working memory and 'everything else' (Lee et al., 2013) through the primary school years and arriving at the fully differentiated three factor structure by the teenage years (Lee et al., 2013).

Development of working memory is well-established both in terms of behaviour (Gathercole et al., 2004a) and brain function, with neuroimaging studies showing that working memory improvements tightly coincide with maturation of the lateral PFC (Klingberg et al., 2002). The gradual myelination of prefrontal connections, the proposed basis for this maturation, is not complete until well into adolescence (Anderson et al., 2001).

Flexibility in switching between rule sets is hard for both the very young and the very old (Cepeda et al., 2001). Young children (around 3 years of age) often have difficulties of ‘perseveration’, meaning that they find it difficult, having learned one rule, to overcome the attentional inertia to apply a new one, even when they can verbally report it (Davidson et al., 2006; Kirkham et al., 2003a, 2003b). This problem, which can be ameliorated by helping children refocus their attention, usually resolves naturally by the time children are 4 or 5. Right into early adolescence, children’s ‘shift cost’ remains greater than adults (Best & Miller, 2010) and there are signs of different processes at play. For example, Huizinga and colleagues found a speed/accuracy trade off whereby, in their study of 7, 11- and 15-year olds, only the teenagers slowed down to ensure a correct response, perhaps because of better strategic reasoning (Huizinga et al., 2006).

Inhibitory control is probably the most multifaceted of the three EC components, with some researchers distinguishing as many as eight kinds of inhibition (Nigg, 2000, 2017). These include ‘executive’ inhibition types such as interference control, cognitive inhibition (‘directed ignoring’), behavioural inhibition and oculomotor inhibition, and various types of selective attention, including suppression of previous irrelevant information and suppression of current information lying outside the attentional field (Nigg, 2000). These different kinds develop at different rates throughout childhood, making a coherent detailed taxonomy of the underlying processes extremely complicated (Munakata et al., 2011; Nigg, 2017). The general picture, as with the other EC components, is of continued, protracted development throughout childhood and adolescence. While overriding impulses, ignoring distractions, and delaying gratification are difficult skills for young children to master, (Diamond, 2013) the benefits of good inhibitory control in the early years have been shown literally to last a lifetime (Diamond, 2013; Moffitt, 2011). There are two points of note regarding the famous early work on delayed gratification (Mischel and colleagues' 'marshmallow test'; Mischel, 1975; Mischel & Mischel, 1987; Mischel et al., 1989, 2011; Shoda et al., 1990): the first is that more recent studies have shown considerable cultural variation in the development of inhibitory control (Sabbagh et al., 2006) and the second is that some attempts at replication using larger and more diverse samples and considering the confound of socioeconomic status, have found (Watts et al., 2018a) that the correlation between an early ability to delay gratification and later educational outcome is much smaller (in some cases, no longer significant), making a simple causal picture less clear.

Can it be improved?

Given the weight of positive life outcomes brought about by better EC, there has understandably been great interest in the potential for training to improve it (Boot et al., 2008; Goldin et al., 2014; Green & Bavelier, 2002, 2008; Rueda et al., 2005; Wass et al., 2011, 2012) and this thesis includes a school-based EC training intervention. A whole host of training activities has been investigated, using approaches as varied as martial arts, mindfulness and aerobic exercise as well as more direct, usually computerised, cognitive training (Cardoso et al., 2018, for a systematic review of interventions in children; also Blair & Raver, 2014; Ericsson & Towne, 2010; Ericsson et al., 1993; Jha et al., 2007; Kamijo et al., 2011; Klingberg, 2010; Melby-Lervåg & Hulme, 2013; Neville et al., 2013; Paananen et al., 2018; Tang et al., 2012; Zelazo et al., 2016), many of which report success. Diamond and Ling (2016) reviewed 84 studies conducted over the last decade which met certain criteria such as control groups, measuring outcomes beyond the immediate (in both time and distance of transfer from the training regimen itself) and not being solely correlational in nature (e.g., comparing EC between children who participated in martial arts vs those who did not). They concluded that, although EC ‘can be improved at any age through training and practice’ that transfer is generally narrow – that is, it improves the specific component trained on (e.g., working memory) but improvements do not generalise beyond that (e.g., no effect on inhibitory control or flexibility; Melby-Lervag & Hulme, 2013). They also found that the gains made were dependent on the amount of time spent practising (Ericsson & Towne, 2010), that EC needed to be challenged, i.e., pushed at the limit of an individual’s capability (Davis et al., 2011) and that the gains seen typically diminish once practice ends (Klingberg et al., 2005). More broadly, they emphasise that the most successful programmes focus not only on the direct training of EC but also its more indirect support – i.e., reducing other factors, such as stress, sadness, tiredness, loneliness and physical ill health which impair its performance (Diamond & Ling, 2016), again emphasising the truism that EC ability does not exist in a vacuum but is highly dependent on other more fundamental aspects of brain function.

It is interesting that, in the long list of ‘burning questions’ posed by Diamond and Ling (2016. p. 42) about EC training, they do not consider the possibility of any downside to improving EC. This is something we will turn to in the next section, as we look at current evidence regarding the relationship between EC and creativity.

What is the relationship between creativity and executive control?

"Cognitive control is a double-edged sword – aiding performance on some tasks when fully engaged, and many others when less engaged." (Amer et al., 2016, p.905)

The nature of the relationship between creativity and control has been the subject of much interest over recent decades (Beaty et al., 2014; Benedek et al., 2014a; Vartanian et al., 2019, 2020). That findings present a messy picture is predictable given the multi-componential profile of both constructs and the fact that it is difficult to compare findings from different levels of description. In particular, 'control' is sometimes conceived broadly, as a general notion of self-control (Baumeister et al., 2007; Carson et al., 2003, Liu et al., 2012) and sometimes narrowly in terms of the specific factors which comprise executive control (Benedek et al., 2014a; Radel et al., 2015; Zabelina et al., 2019). Connected problems concern differences in execution and scoring even when similar task sets are used, and the enormous difference between 'pure' lab measures (e.g., using tests of divergent thinking in the lab) and studies which seek greater ecological validity (e.g., by allowing participants to operate in a domain relevant to them; Fink et al., 2009; Limb & Braun, 2008; Liu et al., 2012). Given the combination of quantitative lab measures and real-world qualitative approaches used in the current research, both types of evidence are relevant and in this section I will give a brief overview of both. I will begin by presenting evidence based on 'control' as conceived broadly, then come on to consider individual EC components, before finally looking at evidence specifically from children.

Control in the broad sense

Creative people have long been characterised as lacking both cognitive and behavioural inhibition (Eysenck, 1995; Martindale, 1999). Evidence from lesion studies, neurodevelopmental disorders (e.g., ADHD) and psychopathology have all found that lower inhibition is associated with higher levels of creativity (Acosta, 2014; Boot et al., 2017; Carson et al., 2003; Sawyer, 2011; White & Shah, 2006, 2011). Carson and colleagues considered the idea that creative individuals are characterised by an ability to 'perceive and describe what remains hidden from others' (Carson et al., 2003, p.499) accounted for by reduced latent inhibition (the ability to filter out information which experience has shown is not relevant), a phenomenon typically associated with schizophrenia. In a set of correlational studies, the team showed that high lifetime creative achievers (as measured using the well validated Creative Achievement Questionnaire (CAQ; Carson et al., 2005a, 2005b) had significantly lower latent inhibition, as measured by their relative failure to filter out irrelevant stimuli in a multiphase auditory task (Lubow et al., 1992). This finding was particularly true for eminent creative achievers, who were 7 times more likely to have low rather than high latent inhibition scores.

Research at the broad level is sometimes framed in terms of a distinction between 'focused' (controlled) and 'defocused' (not controlled) attention (Gruzelier, 2009, 2014a, 2014b, 2014c; Martindale, 1999), often measured with EEG or using neurofeedback, or between 'externally focused' (directly controlled) and 'internally focused' (not directly controlled) attention, often measured with fMRI and associated with the executive control and default mode networks (Raichle, 2015) respectively (Beaty et al., 2015, 2016, 2018, 2019; Chrysikou, 2019; Marron et al., 2018; Sowden et al., 2015a). In a series of EEG experiments, Martindale (Martindale, 1999; Martindale & Hasenfus, 1978; Martindale & Mines 1975; Martindale et al., 1984) studied brain activation during creative ideation. He found that highly creative individuals (in terms of real-world creative achievement) were, during inspiration, characterised by an enhanced state of defocused attention as reflected in increased alpha wave activity – generally taken to be a marker of reduced cortical arousal. Martindale proposed that the looser associational thinking this allowed meant greater activation of the remote associations which produce surprising ideas. Others have taken this idea further, using neurofeedback training to increase the EEG alpha/theta wave ratio and enhance creativity – with some success in both novice and professional dancers and children (Gruzelier et al., 2014a, 2014b, 2014c).

Somewhat more direct evidence of deactivations of the brain's control regions during creative thinking comes from fMRI studies. Limb and Braun (2008) took pains to create a protocol more ecologically valid than psychometric tests. Using a specially designed, scanner-friendly keyboard, they compared brain activations when professional jazz pianists played memorised music sequences with matched sequences during which they improvised new melodies. They found that the improvised sequences were characterised by extensive deactivations within the executive control network (particularly the DLPFC) and focal activation of parts of the default mode network and concluded that "Such a pattern may reflect a combination of psychological processes required for spontaneous improvisation in with internally motivated stimulus-independent behaviors unfold in the absence of central processes that typically mediate self-monitoring and conscious volitional control" (Limb & Braun, 2008, p.1). While studies of improvisation such as the part-music, part-language lyrical improvisation of freestyle rap (Liu et al., 2012) have found similar effects, other studies have not. In a study also using fMRI to look at the brain correlates of improvisation, this time comparing expert with novice musicians, Berkowitz and Ansari (2010) found that the trained musicians showed deactivation in the right temporo-parietal junction in conditions of increased melodic freedom whereas non musicians showed no such changes. The researchers interpret this deactivation as deployment of top down inhibition to prevent distraction during performance of the task, something only the professionals had mastered.

There is a growing body of research looking at the potential for ‘hypofrontality’, as induced by ‘flow’ states (Csikszentmihalyi, 1997; Dietrich, 2003, 2018), by dreaming (Lewis et al., 2018; Stickgold & Walker, 2004; Stickgold et al., 1999) or by hallucinogenic drugs (Carhart-Harris et al., 2016; Girn et al., 2020) to bring creative benefits. *Hypofrontality* refers to the temporary deactivation of the PFC, while ‘flow’ refers to a positive state of immersive engagement in an activity – painting, strumming a guitar, playing Minecraft - which is so deep that actions seem to become ‘effortless, fluid and graceful’ (Dietrich, 2015). There is not the space here to detail these findings, but they are mentioned to highlight the breadth of approaches to considering, directly or otherwise, the creativity/control relationship.

There is an emerging agreement that creativity depends on a unique coupling between brain networks which more usually work in opposition - the default mode network and the central executive network most commonly act antagonistically (Beaty et al., 2015, 2016; Chrysikou, 2019; Chrysikou et al., 2014; Vartanian et al., 2020). Whether this loose accord does any more than deflect the problem up to a new level of abstraction is unclear. It certainly begs new questions: what mechanisms might govern a change in coupling? Does it happen automatically or is it under top-down control or both (Sowden et al., 2015a; Vartanian et al., 2009)? Does it shift during the creative process (Basadur et al., 1995; Sowden et al., 2015a)? Or does the nature of the creative task bring about the switch (Barr et al., 2017)? Is it governed by mood (Pinho et al., 2016)? Or by cultural norms (Ivancovsky et al., 2018)? And is the salience network (a collection of brain regions with key nodes in the insular cortex, responsible for detecting ‘behaviourally relevant stimuli’ and coordinating responses to them; Uddin, 2017) the right candidate for the shifting mechanism (Menon & Uddin, 2010)? Notwithstanding the many unanswered questions, the prevailing notion – that better creativity results from greater flexibility at this higher level – chimes with observations over decades about what makes creative people unique: “One view we have developed on the basis of our studies is that creative persons are characterised not so much by single traits, but rather by their ability to operate through the entire spectrum of human characteristics. So, they are not just introverted, but can be both extroverted and introverted…sensitive and cold, arrogant, and humble, masculine, and feminine, as the occasion demands” (Csikszentmihalyi, 2014 p. 170).

EC components

Coming to the more specific evidence regarding executive control, Zabelina and colleagues set the scene (Zabelina et al., 2019), taking from Miyake et al.’s (2000) approach to look at the unity and diversity of executive control in creativity. They examined whether working memory, shifting and inhibition predicted creativity, operationalised by self-report creative achievement, lab tests of divergent thinking and whether participants were employed in artistic (creative) vs Information Technology (IT – i.e., not creative) professions. Multiple regression analysis, controlling for general cognitive ability, education level, age, and gender, found that better working memory predicted higher fluency in divergent thinking; no other single factors showed any significant effect with divergent thinking (DT). Real world creative achievement was significantly predicted by better response inhibition for the artists and by poorer shifting ability for the IT professionals, though both effects were small. Finally, professional involvement in the arts was associated with better common EC (a composite measure computed by averaging z-scored inhibition, updating, and shifting scores) as well as better shifting ability, compared to IT professionals. The authors conclude that the extent to which aspects of EC predict creativity depends on how it is operationalised.

Taking a different approach, Benedek and team used latent variable analysis to look at the relationship between creativity and executive control (Benedek et al., 2014a) in a sample of 243 young adults. Administering a battery of lab tests (four for divergent thinking - scored by raters on a single measure of 'creativity'), they found that both updating (working memory) and inhibition, but not shifting ability, predicted creativity scores. No significant correlations were found between the latent factors of updating, inhibition and shifting. The results are surprising both for the lack of overall cohesion of the EC measures and the fact that flexibility, often seen as a key feature of creative success, showed no relationship here, suggesting that lab measures of switching and the sort of flexibility of thought required for creative thinking might be some distance apart. These sort of inconsistencies in findings sometimes arise when different tests are used to represent EC components – here, it is possible that the single test used to represent switching (a number letter task; Rogers & Monsell, 1995) was not the most relevant for creativity.

Inhibitory control

A commonly proposed role for EC in divergent thinking tests is that of inhibitory control, said to be needed to block the obvious, common, outlawed or repeat responses likely to arise from spontaneous associative thinking (Beaty & Silvia, 2012; Benedek et al., 2014a; Cassotti et al., 2016; Edl et al., 2014; Mayseless et al., 2015a, 2015b). Evidence for this view comes from several studies which distinguish between the generative and evaluative dimensions of the creative process (Beaty & Silvia, 2012; Mayseless et al., 2015a, 2015b). Beaty and Silvia examined the serial order effect, the well-known observation that better (more original) ideas tend to appear later than obvious ideas, a finding traditionally explained by a 'spreading activation in semantic memory' (Mednick, 1962). The researchers' contrasting view was that the improvement in creativity over time was accounted for by increased influence of top-down executive control, something they set out to measure by subjecting their participants to a full 10 minutes thinking about alternative uses for a brick (Beaty & Silvia, 2012). Operationalising EC as fluid intelligence with a six-test battery, they time stamped each AUT response and used multilevel structural equation modelling to look at the within-person effect of time. Their findings showed that while fluid intelligence did not predict fluency, it did interact with time, such that as intelligence increased, the serial order effect diminished, i.e., for those high in fluid intelligence the creativity of their responses was less dependent on time. They take this evidence (which they concede is 'indirect and oblique') to mean that those who are more effective at 'managing their minds' can draw on effective idea generation strategies 'despite interference generated from obvious ideas and entrenched ways of thinking.' Replication involving more typical tests for EC, as opposed to the looser 'fluid intelligence' would be helpful.

Cheng and colleagues (Cheng et al., 2016) used a similar method of time stamping to look at the role of inhibition in a problem finding task and found that the role of inhibitory control varied according to when in the task one looked. Relative to those with higher inhibition, lower inhibition was associated with better ideational originality in the early stages of a divergent thinking task, but with worse ideation later on, a finding which the authors interpret in line with models (e.g., Nijstad et al., 2010) which suggest that associational thinking early on in ideation yields to a more strategic controlled approach as spontaneous ideas run out.

Some studies assessing inhibitory control using Stroop performance have reported a positive correlation between inhibition and divergent thinking performance (Edl et al., 2014; Groborz & Necka, 2003) but some experimental studies have found the opposite. Radel et al. (2015) used a within-subjects design to test the effects of depleting inhibition (so called 'ego depletion') as an alternative way of manipulating levels of inhibitory control. The idea is that enduring taxing inhibitory control tasks leads to a temporary reduction in inhibitory control, since executive control cannot be maintained indefinitely (Schmeichel, 2007; Schmeichel & Baumeister, 2010). Hypothesising that inhibitory control would be beneficial to convergent thinking tasks but detrimental to DT tasks, the team tested participants on multiple occasions over a week, with different levels of inhibitory control task demands immediately before completing creativity tests of each type. They found, in line with their predictions, that exposure to the high demand inhibitory control task led to higher fluency in the AUT but had no effect on performance in the convergent task This finding suggests that inhibitory control might play contrasting roles in different aspects of creativity. Excessive inhibitory control might well be unhelpful during divergent, generative thinking, which requires less goal-oriented and more ‘playful’ thought. By contrast, when the goal is to converge on a single right answer, inhibitory control might be helpful to rule out inappropriate responses and home in on the correct one.

One explanation for the contradictory findings regarding the effect of inhibitory control is that ‘inhibition’ can be over-simplistically characterised. For example, when Cassotti et al. (2016) claim that inhibitory control can support creativity because the “ability to think of something new and original requires first inhibiting spontaneous solutions that come to mind quickly and unconsciously”, they are referring to a single limited definition of proactive cognitive inhibition. In reality, inhibition is composed of a broad range of cognitive, behavioural, and social dimensions. It is quite possible that inhibition “can serve to enhance creative thinking in some instances while impairing it in others” (Storm & Patel, 2014, p. 1597) and it is likely that “the variety of conceptualisations of inhibition may also be one reason for the number of apparently inconsistent findings in the literature” (Benedek et al., 2012, p. 484).

Working memory

There is less empirical evidence regarding the relationship between working memory and creativity (Benedek et al., 2014a), in part because it is less contentious: unlike inhibitory control, there is no theoretical reason why better working memory might be detrimental. In addition to the Zabelina et al. study already mentioned, other studies have found positive correlations between lab measures of working memory and fluency and originality in DT tasks (De Dreu et al., 2012; Oberauer et al., 2008). Others have found no direct relationship (Lee & Therriault, 2013).

Shifting

There is strong consensus that creativity requires flexibility of thought at a macro level. For example, in personality trait measures of 'openness to experience', lab findings have shown that creative (more open) people show less filtering of task-irrelevant information, suggesting that being 'open to experience' manifests at the sensory level (Antinori et al., 2017; Beaty et al., 2018; Kaufman & Sternberg, 2019), as well as the micro level (e.g., in being able to flexibly shift from one strategy to another (Nijstad et al., 2010; Zabelina & Robinson, 2010a). The notion that flexibility is strongly connected to creativity is even baked in to some DT tests, where flexibility is one of the key sub measures (Benedek et al., 2014a; Guilford et al., 1978; Torrance, 1974) - though clearly ideational flexibility 'cannot serve as independent evidence for creativity and flexibility at the same time' (Benedek et al., 2014a). Confusion in terminology can also obfuscate: in Diamond's influential EC work, she defines EC in such a way as to absorb creativity within it, suggesting cognitive flexibility means "creatively thinking 'outside the box'" (Diamond, 2013, p. 135). Despite linguistic overlaps, there is little empirical evidence. Instead, evidence comes indirectly, such as from intervention studies which have found that inducing positive mood has positive effects on both cognitive flexibility and creative problem solving (Ashby et al., 1999; Rowe et al., 2007) and from micro-analyses of Stroop measures showing that individuals scoring higher on creative thinking tests show more flexible cognitive control, as defined by greater control modulation from trial to trial (Zabelina & Robinson, 2010a).

Here again, as with inhibition, the problem might lie in the level of description at which flexibility is being conceived and described. Sometimes, cognitive flexibility is framed in terms of attention – and in such a way that it even becomes detached from the broader idea of executive control. Vartanian (2020), also citing Gabora (2018) says, “Considering a concept (e.g., brick) in a new context (e.g., needing a doorstop) also requires a shift in attention, and such a shift can arise spontaneously due to the sparse, distributed, content-addressable nature of memory…Such shifts, to the extent that they are spontaneous and reflect overlap in distributed representations, would appear to involve the default-mode network (DMN) rather than the executive control network (ECN)” (Vartanian, 2020, p.9).

Evidence from children

There is “a trade-off between the ability to explore creatively and learn flexibly, like a child, and the ability to plan and act effectively, like an adult” (Gopnik, 2016, p. 9).

Although there has been much interest over the years in the relationship between intelligence and creativity in children, studies of the relationship between EC and creativity, particularly any using DT tasks, are rare. One of the few studies to consider it directly looked also at a possible mediating role for EC in the relationship between intelligence and creativity (Krumm et al., 2018). Participants were 209 children aged 8-13 who completed tests for shifting, working memory and inhibitory control (EC), the Torrance figural tests and the Creative Intelligence test (Corbalán et al., 2003), which required them to formulate questions around given stimuli (creativity), and three intelligence tests. Using hierarchical regression analyses, the researchers found that inhibition and shifting, but not working memory, predicted creativity when controlling for intelligence. Further analysis looking at mediation effects suggested that in fact shifting was the chief driver; when both shifting and inhibitory control were included in their structural equation model, all the variance between inhibition and creativity was explained by shifting.

A different finding emerged from an experiment (German & Defeyter, 2000) looking at children's experience of functional fixedness (Duncker, 1945). This is the finding that people's knowledge of an object's typical function hinders them from considering it in alternative ways. Using a version of Duncker's candle task adapted for use in young children (Bobo the bear can't reach a shelf with his toy on; solving the problem means having to use the box presented as Bobo's house to make the tower of items sufficiently tall), they assigned one group to a 'pre-utilisation' condition in which they were shown the object (i.e., the box)'s conventional use while the other group had no such introduction. They found that while the 7-year-olds solved the task quicker and in higher percentages than the 5-year-olds in the no pre-utilisation condition, in those who had experienced the object's use, it was the reverse: 60% of 5-year-olds compared to 40% of 7-year-olds solved the problem – and in less than half the time of the older children. They suggest that this finding is explained by one of two things: either younger children have a more flexible attitude to object function or the exact opposite – that they have an impoverished idea of function which means there is no prepotent response (or functional fix) requiring inhibitory control to suppress.

Cassotti and colleagues (2016) claim that inhibitory control is a core process of creative problem solving throughout childhood, mainly based on theory and some evidence from the adult literature. They cite one developmental neuroimaging study (Kleibeuker et al., 2013a) looking at adolescents and adults, which showed that brain regions (specifically, the inferior frontal gyrus (IFG) and the dorsolateral prefrontal cortex (DLPFC)) typically associated with EC - and inhibitory control in particular - were more activated when participants provided successful solutions in matchstick problem-solving tasks, and that the relative activation was even greater in adolescents compared to adults. They attribute this not to the traditional view that the increased activation reflects insufficient recruitment of later-developing brain regions (Crone & Dahl, 2012), i.e., the idea that these regions are having to work harder, but to an alternative view that adolescence, a time of learning independence, requires a more exploratory and flexible mindset, i.e., that the increased activation in these regions is adaptive. This pattern could also be explained by adolescents relying more on on-line computation of the solutions, while adults rely more on retrieval strategies from memory.

Van Reet used an ego depletion paradigm to study pretend play (as an example of real-world creativity) in pre-schoolers (Van Reet, 2015). Pretend play is a complicated behaviour to study with regard to inhibitory control: is inhibition required to inhibit typical behaviour in order to pretend something that is not real? Or is inhibition undesirable in that it might impede the leap into the unknown that pretend play requires? In a series of studies, Van Reet tried to differentiate the effect of ‘conflict inhibition’ (the control required to stop a prepotent response in a motor response task such as Luria’s hand game (Luria, 1976)) from ‘delay inhibition’ (the control needed to wait, as in a go/no go task) on subsequent pretend play. Findings were nuanced; children who had experienced cognitive depletion through conflict inhibition tasks immediately before play showed subsequently better pretend play (measured by more use of imaginary objects, more elaborate pretence actions and length of pretence) while those experiencing depletion through delay inhibition showed no such effects. This experiment is another useful reminder that inhibitory control should not be construed as monolithic.

Again, as with research in adults, some researchers take a broader view of control (Gopnik et al., 2015; Thompson-Schill et al., 2009). Gopnik has carried out several studies based around the idea that adults ‘know more and explore less’ while children, who are still learning about the world, necessarily take a different approach. Her well-known ‘blicket detector’ (Gopnik et al., 2000, 2004; Griffiths et al., 2011; Kushnir & Gopnik, 2005; Lucas et al., 2014), a machine more likely to light up and play music when certain combinations of colourful blocks are put on top of it, found that 4-year-olds efficiently learnt abstract principles of causal relationships, using statistics consistent with Bayesian learning, to predict correct combinations. Moreover, they generalised better than adults when a new unconventional relationship was presented, a finding that the researchers attributed to adults being more reluctant to let go of previous successful principles (Lucas et al., 2014). The idea that creative cognition might benefit from an absence of cognitive control is shared by others (e.g., Blackwell & Munakata, 2014; Thompson-Schill et al., 2009) and even led Gopnik to propose that the long childhood experienced by human children (a protracted period of underdeveloped prefrontal cortex and lots of exploratory play) is evolution’s way of protecting the research and development department of the human species (Gopnik, 2016).

Current methodological approach

How to “gain insights into someone’s mental processing as they create…is one of the most intractable problems of creativity research” (Sowden et al., 2020, p.314). What lies between the setting of a creativity task and the delivery of creative output still contains many mysteries; while it is straightforward to measure someone's 'original and valuable' ideas for what to do with a paperclip or their success at producing a remotely associated word, how do we measure *how* they actually produced those ideas? Did ideas arise spontaneously? Or were they actively sought out using strategies that can explicated? Do individuals favour a particular approach or do they use a mixture of approaches? And if it is a combination, is the principal variation over time within individuals, or across individuals tending to be creative in consistent ways? Answering these sorts of questions about an individual's creative process involves doing something that has been rather foreign to psychological research in this area: asking them.

The reluctance to utilise 'introspective reports' to examine cognitive processes is explained in large part by one of the most cited (over 14,500 citations in October 2020) papers in the psychological sciences, Nisbett and Wilson's (1977) 'Telling more than we can know'. It reports on a series of experiments in which participants are asked to give explanations about their behaviour which has been, unbeknownst to them, covertly manipulated. Nearly all give explanations which do not include the manipulation, leading the authors to conclude that, "There may be little or no direct introspective access to higher order cognitive processes" (Nisbett & Wilson, 1977, p.231). This work, subsequent replications, and critiques (Fazelpour & Thompson, 2015; Johansson et al., 2005, 2006; Petitmengin, 2011; Petitmengin et al., 2013; Shear & Varela, 1999) will be considered in detail in Chapter 3. For now, the important point is that evidence shows that, with the right techniques and conditions, this bleak verdict on the value of self-report for cognitive insight need not be inevitable. Indeed, several creativity researchers have highlighted a need to be more open to these approaches, "Creativity could benefit from greater valuation of subjective self-reports from participants" (Barr, 2018, p.28), particularly given the unique phenomenology of creativity itself (McPherson & Limb, 2013; Warr et al., 2018). Verbal qualitative techniques (e.g., 'think aloud' protocol analysis and stimulated recall interviewing) have been used in a few studies to investigate the creative process in adults (Després, 2021; Gilhooly et al., 2007; Khandwalla, 1993; Pringle & Sowden, 2017a). They have also been used, albeit even more rarely, to investigate children's thinking in areas such as reading comprehension strategies (Meyers et al., 1990) and self-regulated learning (Heirweg et al., 2019; Vandevelde et al., 2015). Think aloud protocol analysis has also been used to study the creative process in undergraduates (Ruscio et al., 1998) but to my knowledge, there are no such studies in children.

As part of this thesis, verbal qualitative reports from primary school children will be used to gain insights into their creative process and the extent and nature of their evocation of executive control processes in it. Some of the processes involved will be readily accessible by introspection – for example, description of developing a strategy to find unusual ideas by focusing a search on words beginning with unusual letters (q, z, j). Other relevant parts of the process might be less readily accessible – for example, describing the processes which result in an idea just arising spontaneously with no strategy or directed attention. These reports will be used in conjunction with quantitative lab approaches using the divergent thinking tasks described in detail above.

As well as the novel qualitative approaches, this thesis will also include a training study. Its goal will be to bring about improvements in EC through training, then evaluate resulting effects on creativity. Given that the other studies here are correlational, this manipulation of the system is an important step in trying to establish a causal role (positive or negative) for EC in children's creative process. The particular challenges of training paradigms, including the difficulty of trying to differentiate practice and developmental effects from the effects of training, as well as the challenges of putting EC training techniques 'into the wild' of the classroom, will be covered when we introduce the training study in Chapter 5.

The rationale of this 'mixed methods' methodology (defined as the collection and analysis of both quantitative and qualitative data; Creswell & Clark, 2011; Tashakkori & Teddlie, 2010) is that combining quantitative and qualitative approaches provides a fuller, more rounded understanding than either method alone (Fetters et al., 2013). In particular, here the quantitative aspect will measure creative product while the qualitative will focus on the creative process. Given the imperfections of any single approach to studying creativity, it is "a useful strategy to employ multiple approaches and experimental designs to directly or indirectly investigate the same operations of creative cognition" (Abraham, 2018, p. 170), and an important attempt to address the low convergent validity of different creativity test measures (Kaufman, 2003; Sternberg & Grigorenko, 2003; Yoon, 2017;) compared to lab tests and real world creativity (Benedek et al., 2017; Carson et al., 2005a, 2005b).

Creativity presents as a special case for the suitability of mixed methods for other reasons. We have seen there are particular issues – of time, motivation, domain specificity, fragility, whimsy – with quantitative lab measurement of creativity, as well as a problem of more specific concern for the current investigation: that the nature and context of lab tests themselves tend to conjure executive control, meaning EC involvement in creativity in the lab might differ from that 'in the wild'. These matters make it prudent not to rely solely on evidence from psychometric tests, though these remain the most reliable tools for generalising beyond the current work. Qualitative research too, requires care and reflexivity, with robust questions asked about the validity of the data as well as their wider generalisability.

Bringing together quantitative and qualitative data is not an easy task, either theoretically or practically (Yardley & Bishop, 2008). Theoretical problems can stem from epistemological incompatibility of approaches, while pragmatic problems arise from the sheer complexity of assessing highly diverse data (Willig & Rogers, 2017). Some argue for an approach which keeps different data types essentially distinct; in Mason's 'facet methodology' (Mason, 2011), the overall research question is a gemstone, with different facets reflecting different lines of enquiry and different ways of seeing. Understanding comes not from maximising data production but from an emphasis on the significance of 'the flashes of insight offered up by different facets' (Mason, 2011, p.75). At the other end of the spectrum are pragmatic approaches, in which the quantitative dimension often leads, with qualitative data adding texture and depth (Yardley & Bishop, 2008). An ideal for a fully triangulated design is one in which different but complementary data are obtained on the same topic (Johnson et al., 2007; Morse, 1991) and brought together in such a way that the results, through cross verification from multiple sources (Creswell & Clark, 2011; Fielding, 2010) are both robustly laboratory tested and ecologically valid.

In the current work, the mixed methodology, and triangulation, in particular, has evolved over the course of the study.

Aims and outline

The main goal of the thesis is to better understand the role that executive control plays, positively and negatively, in children's creativity. Specific questions are:

- To what extent are there individual differences in the role EC plays?

- Does inhibitory control have a detrimental effect on children's creativity (by excessively narrowing the potential ideational search space)?
- What is the effect of training EC on children's creativity?
- Does the effect of training differ between individuals?

The thesis will focus on children of primary school age. This choice of age is principally motivated by the desire to address research questions in the context of education – specifically, on the current emphasis on EC to improve school achievement. In our consideration of 21st century skills, have we got the balance right?

The thesis will be structured as follows:

Chapter 2 will look at the underlying relationship between EC components and divergent thinking ability in a group of primary school children aged 5 to 11. What do psychometric tests tell us about the relationship between these constructs? How do EC and creativity components develop over this age range and what similarities and differences are there in their trajectories?

Chapter 3, drawing a small group from the sample in the previous study, invites children to complete a creative activity and then describe the process in detail. Using video stimulated recall and a task involving drawing or making up a story (they choose), children are prompted to describe their unfolding creative process through semi-structured interviews which are then assessed through theoretical thematic analysis. The structured questions aim for insight into executive control processes while the open nature of the interviewing also allows new insights, not derived from theory, to be evaluated.

Chapter 4 is the first attempt to triangulate quantitative and qualitative data, asking whether characteristics of children's qualitative responses predict their performance in quantitative tests.

This chapter depicts in honest detail some of the challenges presented in bringing diverse data sources together and ends with specific proposals about how to make the task more tractable.

Chapter 5 is one of three chapters using data from an EC training intervention study carried out on 156 children in years 4 and 5 in London primary schools. This chapter focuses on the quantitative findings, using linear mixed modelling to look first at whether the EC training succeeded in improving EC and second, at whether there was any far transfer to children's performance in creativity tests.

Chapter 6 is a nested qualitative study, involving 16 children who were also part of the training intervention. Again, using stimulated recall and thematic analysis, the children were asked about their creative process completing a version of one of the same divergent thinking tests used in the quantitative study, to allow for more direct comparison of children's responses. The questions focused on the involvement, or exclusion, of control processes.

Chapter 7 is a second attempt at triangulation, assimilating learning from the first, including using a consistent creativity test across both quantitative and qualitative studies and a fixed set of questions. Qualitative analysis led to the delineation of creative sub-types, based on different descriptions of process. These sub types were used to make predictions about the possible differentiation of the effects of EC training on creativity across children, and these differential predictions were then tested against the quantitative results.

Chapter 8 discusses findings across the thesis, highlights limitations and points to possible future directions of research in this area. What have we learned about the relationship between EC and creativity in children? Finally, the chapter broadens out to consider current educational approaches to EC and creativity, and to speculate on whether children's '21st century skills' might be better supported by altering the balance of the current approach.

Chapter 2. Cross-sectional exploration of the relationship between creativity and EC across primary school ages

Introduction

Chapter 1 described some of the conflicting evidence regarding the role executive control plays in creativity (Amer et al., 2016; Barr et al., 2015; Chrysikou, 2019; Chrysikou et al., 2014; Thompson-Schill et al., 2009). Since EC and creativity are both complex, multifaceted constructs, the contradictions are perhaps unsurprising: effects are likely to be nuanced, vary according to task and context, and interact with many other creativity-relevant factors including motivation (Collins & Amabile, 1999), time (Plucker et al., 2006), emotional state (Pessoa, 2009), domain knowledge (Baer, 2010), experience (Fink et al., 2009), constraint level (Cummiskey & Baer, 2018) and more. This is in addition to the diversity within EC factors themselves and the evidence that even within a factor (e.g., inhibitory control) there might be different effects depending on the stage of the creative process (Beaty & Silvia, 2012), the type of inhibition (Van Reet, 2015) and even the instructions given (Nusbaum et al., 2014). Added to this are the many issues with creativity tests themselves (Runco, 2008). The conflict nonetheless presents the first problem in formulating precise hypotheses, with a second arising from the paucity of evidence from children.

This study is a first step in trying to address these problems by rendering the broad question (of how executive control processes contribute to children's creativity) more tractable, in two ways. The first involves deconstructing both creativity and EC to look at the relationships between their components - both within and between the constructs and in different creative domains. Here, we are looking for evidence through patterns of correlation. The second involves looking at developmental trajectories (using a cross-sectional approach with children across the primary school age range) of each construct component and their patterns of similarity and difference, i.e., here, we are considering the effect of age on performance. The goal is to find firm evidence of relationships which will pave the way for further, more detailed investigation. High positive correlations between inhibitory control and originality, for example, might suggest that inhibition might act on the critical evaluation of ideas, allowing new research questions to be specified; high positive correlations between working memory and fluency would bolster a theory that the ability to mentally play with multiple items from memory and the senses could aid the production of a greater quantity of ideas, again suggesting a clear direction for further investigation. So, what does the available evidence lead us to expect?

Empirical evidence on the relationship of EC components to creativity

The evidence regarding working memory is, with a low bar, the most consistent. WM, as measured, for example, with tasks requiring updating memory of changing sequences of numbers, letters, or category contents (Friedman et al., 2016) has been found to be positively associated with fluency in the Abbreviated Torrance Tests for Adults (ATTA), a mix of verbal and figural DT tests (Zabelina et al., 2019). In another study, WM, measured with a non-verbal 2-back task involving abstract shape recall and a single overall creativity measure, comprised of composite scores (incorporating both quantity and quality measures) from four verbal DT tests in a latent variable analysis again showed a positive relationship (β=.29) (Benedek et al., 2014a). De Dreu and colleagues (2012) hypothesised that working memory would be relevant to creativity in enabling ‘persistent, focused, and systematic combining of elements and possibilities.’ In a varied set of studies, ranging from musical improvisation to insight tasks and a novel idea-generating brainstorming task, they looked at correlations with WM, measured with a delayed serial recognition task which involved participants seeing 8 words or images in sequence then, after a short pause, having to say if a subsequent word or image was a part of the original set. Their findings found that this measure of WM did indeed seem relevant to creativity, with high correlations (e.g., .41 for fluency and .63 for originality in the DT task). The authors conclude that working memory capacity "benefits creativity because it enables the individual to maintain attention focused on the task and prevents undesirable mind wandering" (De Dreu et al., 2012, p.656) a description that suggests a broad characterisation of WM. Finally, Lee and Therriault (2013) attempted to unpick the relationship between WM, intelligence and creativity, using a range of creativity tests including the AUT and the ATTA and two measures of WM, one a backward digit span task, one a visuospatial task in which participants must decide whether a presented shape is symmetrical while committing to memory the position of a red square on a matrix. They conclude that WM operates indirectly, via intelligence and associative fluency, to predict DT scores, though on its own WM did not predict DT scores and no creativity sub measures were significantly correlated with either WM score.

- On the balance of this evidence, we would tentatively expect to see a positive correlation between WM and DT test measures, particularly for fluency in verbal tests.

Turning to flexibility, and focusing on flexibility as construed in EC tasks rather than in its broader characterisation (Antinori et al., 2017; Diamond, 2013), the same latent variable analysis mentioned above (Benedek et al., 2014a) found that shifting did not significantly predict divergent thinking ability (β=.03, n.s), a finding replicated in a similar study which showed shifting predicted neither fluency nor originality in DT, though better shifting ability was seen in those involved in artistic professions (Zabelina et al., 2019). Zabelina and Robinson (2010a) considered the question of whether the key characteristic of highly creative people is not their level of cognitive control per se, but their enhanced ability to modulate it – a sort of higher-level flexibility. They considered this, again using the ATTA and here operationalising flexibility via the Stroop test. As well as calculating the congruent-incongruent RT difference as the typical

'Stroop effect' (a typical inhibition measure) they looked at the effect on RTs of switches from congruent to incongruent trials and vice versa, using a within-participant 2x2 design considering both priming and target congruence/incongruence. Flexible cognitive control, they argue, is represented by smaller target congruency effects after incongruent primes and a larger effect after congruent primes, i.e., flexible people relax cognitive control when it is not needed (i.e., after congruent trials) but employ it more fiercely when it is (i.e., after incongruent trials). They then used GLM analysis (as a way of including both this within-participant variance and the between-participant variance in originality scores on the ATTA) and found a significant three-way interaction between ATTA originality x prime congruence x target congruence. Further investigation showed that, while all participants showed some flexibility of control, those with high originality showed significantly more (with a medium effect size, r=.29), supporting their idea that it is higher flexibility rather than higher control that predicts greater originality.

- The prediction here, based on the balance of evidence, is that flexibility might show little correlation with DT test scores, though we might see positive correlation with originality in verbal tests. For figural tests, it is hard to make any prediction based on the evidence.

The evidence regarding inhibitory control is the most contradictory. Some researchers testing theories based on a broad definition of cognitive control suggest that, particularly for children, lower control might benefit the unconventional thinking that defines creativity (Amer et al., 2016; Thompson-Schill et al., 2009) while others show the opposite, suggesting that creative ideas are enhanced by greater ability to apply top-down control over attention and cognition (Beaty & Silvia, 2012; Beaty et al., 2014; Gilhooly et al., 2007). Looking specifically at research using DT tests, we see the same conflicting findings. Edl and team (2014) compared undergraduates on creatively demanding courses (e.g., design) with those taking non-creative courses (e.g., psychology) on performance on the Stroop test and verbal and figural DT tests including the TTCT. While the non-creative group showed, as expected, a strong Stroop effect, the creative group showed no effect, i.e., RTs did not significantly differ between congruent and incongruent trials, suggesting high control. On DT tasks, they found that better Stroop performance (i.e., lower RTs) was associated with higher fluency (but not higher originality) in the verbal domain and higher originality (but not higher fluency) in the figural domain. The study was limited by small numbers (30 in one group, 31 in the other) and the big assumption about each group's underlying 'creativity'; i.e., it is conceivable that psychology undergraduates might in fact be creative.

A similar finding (Camarda et al., 2018) comes from an experimental manipulation using a dual-task paradigm, again involving the Stroop and a novel DT test (participants had to think of ideas to ensure a hen's egg does not break when dropped from a height of 10 metres). Participants were randomly assigned either to a single task group (DT task only), an inhibition dual task (DT task plus a taxing version of the Stroop task involving all incongruent trials) and a control dual task (DT task plus Stroop involving all congruent trials) and scores were calculated for fluidity (equivalent to fluency), flexibility and expansivity (a measure of participants' ability to 'think beyond the obvious' and thus a proxy for originality). The manipulation design proposes a carry-over effect from the more taxing IC task which might influence subsequent creativity. Planned contrasts on the main effect found for condition showed that, while there were no differences between the single task and control dual task groups, those in the inhibition dual task group had significantly lower scores for both fluency and expansivity.

Indirect evidence for the importance of inhibitory control comes from studies looking at the neural underpinning of originality. Mayseless and team used fMRI to look at originality in AUT performance, using the frequency method (i.e., a measure based on statistical rarity rather than rater judgement) to score originality. For the AUT, participants had to respond with an original use for a familiar object, while in the control condition they had to name a characteristic of the same object. Activation patterns suggested that areas in both the DMN and the ECN were involved in producing original ideas, a finding the researchers attribute to the need for both associational processes to make novel, surprising connections, and inhibitory control to attenuate conventional thinking (Mayseless et al., 2015a).

Other research suggests that reduced inhibitory control might benefit creativity. One example is a repeat measures experimental study on an undergraduate sample, which sought to directly manipulate inhibitory control levels by exhausting them (Radel et al., 2015) and again used the AUT to look at the effects on fluency, flexibility, and originality. Participants were tested in two separate sessions; each began with a Flanker task (Eriksen, 1995) a typical inhibitory control task in which participants must respond with a key press corresponding to the direction of an arrow on screen, with surrounding arrows pointing either in the same (congruent) or the opposite (incongruent) direction. This was to assess baseline performance and was followed by the Simon task (Simon, 1990), another conflict task, in which participants respond with a left or right key press in response to the colour of a green or red circle appearing left or right of screen. In congruent conditions, the key press is the same side as the stimulus; in incongruent, it is the opposite, requiring participants to inhibit an automatic response. A second Flanker task was then carried out to compare to baseline (as confirmation that the Simon task had impacted inhibitory control) before participants immediately completed the AUT. The experimental manipulation involved changing the cognitive demand of the Simon task: on one testing occasion demand was high with 50% of trials being incongruent, while on the other it was low, with only 10%

incongruent trials. The results showed that participants exposed to the high inhibitory demand condition (i.e., whose inhibitory control was more depleted as shown by poorer performance on the second Flanker task, going into the AUT) had significantly higher fluency and originality scores on the AUT than in the low demand condition. There was no effect on flexibility nor elaboration. When the team replicated the experiment (swapping Simon and Eriksen tasks so that Simon became benchmark and Eriksen manipulation), they found similar results; participants in the high demand still had significantly higher fluency in the AUT, though this time coupled with higher flexibility rather than higher originality. The researchers do not report the use of Bonferroni or other methods for correction of multiple comparisons.

- The evidence described reflects the state of contradiction in the field regarding the role of inhibitory control in divergent thinking. For present purposes, it means there is not a solid empirical basis from which to make strong predictions for what we will find.

Divergent thinking tests: methodological conundrums

There has been a tremendous amount written about divergent thinking tasks and the conceptual and practical problems with them (e.g., Abraham, 2018; Dietrich, 2015; Forthmann et al., 2018; Plucker et al., 2014; Reiter-Palmon et al., 2019; Runco, 2008, 2014, 2017b), some of which has already been outlined. The decision to use them here, despite their many problems, is based first, albeit circuitously, on the fact they remain by far the most used tests in creativity research with reasonably well-established reliability, second that they are suitable for children and finally, as a fledgling researcher, for the need to situate my findings in the familiar.

The reliability of DT tasks depends on many factors such as domain (verbal or figural), time given, and familiarity with the stimuli used (Forthmann et al., 2016) as well as the instructions given (Nusbaum et al., 2014). For these reasons, researchers emphasise the importance of assessing performance using multiple DT tasks, rather than relying solely on one (Reiter-Palmon et al., 2019); in the current study, to try to improve reliability as suggested, three different DT tests (two verbal and one figural) will be used. We are still left with the vexed problem of the sub scores and the obscurity of the information they are conveying. Let us take an example: divergent thinking tasks are sometimes misconstrued as being entirely generative in nature (Dietrich, 2015). In fact, producing ideas for alternative uses of an object involves both generation and evaluation – baldly, having an idea then deciding if it is any good (Runco, 2014) such that the divergent / convergent distinction is really more a continuum (Eysenck, 2003) and it is almost impossible to think of a creative task which does not (at least potentially) use both types of process. The difficulty comes when we try to use scores to differentiate mechanisms; a child who produces one answer might only have generated one idea, or they might have generated 10 but ruled 9 of them out. In both cases, they would receive a fluency score of 1. If we then look at the relationship with EC components, what are we really looking at? In the case of the first child, we would be looking primarily at idea generation (likely to be less EC dependent) and in the second, primarily at evaluation (likely to be more EC dependent) but we have no way of knowing which it truly is. There is a good deal we cannot deduce from the scores. Nonetheless, fluency remains our best available clue about generation.

Originality presents its own challenges, as have been outlined, of both a mathematical and a conceptual nature (Forthmann et al., 2020a, 2020b; Plucker et al., 2014; Reiter-Palmon et al., 2019). Again, the mechanisms by which originality can be achieved are multiple and scores do not enlighten us about processes, but we can make some inferences. Let us take another example. A child coming up with alternative uses for a pencil, produces the response ‘Use the lead in it to poison my sister’. That response would be certain to score highly for originality, whether it is scored by raters or by statistics, because it is an unusual and imaginative answer. What difference does it make if that response is the child's only response or just the most original among 10 responses? In terms of scoring, the difference could be profound; if using a summing approach, the more fluent child would benefit greatly; if using a ratio approach, they would be severely penalised. But even setting aside the complex question about which child really is the more original (i.e., what scoring method best represents their originality) can the scores help us make any reasonable assumptions about the processes which lie behind them? It seems reasonable to assume that the child with only one brilliant answer has exerted more evaluation to produce it than the fluent child, who might have produced it through the sheer exuberance of their generative abilities. On this basis, originality – with the important caveat that it be scored according to ratio methods - is our best proxy for evaluation.

The other two measures will be discussed in less detail. The flexibility measure is a hybrid, lying between the quantity measure 'fluency' and the quality measure 'originality', making it doubly hard to interpret, although easier to score. Elaboration is largely a measure of the level of detail in responses, something which most consider less a critical component of ideation (Hornberg & Reiter-Palmon, 2017; Reiter-Palmon et al., 2019); it is a reliable measure which, though time-consuming, is relatively straightforward to score.

Developmental trajectories

On the EC measures, we would expect to see a steady development of working memory over this age group (Anderson, 2002; Diamond, 2013; Huizinga et al., 2006). For flexibility and inhibitory control, we would also expect to see improvements with age, but possibly with a less smooth trajectory, reflecting greater variation in the timing and rate of maturational change (Huizinga et al., 2006; Lee et al., 2013). On the creativity measures, we expect developmental trajectories to be bumpier (Barbot et al., 2016; Beghetto and Kaufman, 2010; Saggar et al., 2019; Said-Metwaly et al., 2020) and potentially to see distinct trajectories for different tasks, particularly in different domains (Claxton et al., 2005; Runco, 2016; Said-Metwaly et al., 2020). Considering sub measures, elaboration is founded on better dexterity, language improvements, more experience and faster processing and as such is a clear candidate for straightforward improvement through the primary school years (Kim, 2011). Fluency, too, should improve as older children have accumulated more experience to act as substrates for ideas (Charles & Runco, 2001; Runco & Acar, 2010), though this might be mitigated by older children feeling more self-conscious and more reluctant to offer up non-conformist ideas (Barbot et al.,2016). Originality is the hardest to predict since there is the most conflicting evidence regarding its trajectories and a lack of longitudinal data. Based on the assumption explicated above that originality is our best representation of evaluative skills, we would expect to see improvements (Charles & Runco, 2001; Lau & Cheung, 2010), but issues related to testing, particularly children's perception as they reach mid childhood that 'tests' of any kind must involve predictable answers (Runco, 2016), as well as emotional factors such as increased self-awareness and a desire to conform (Barbot et al., 2016), might suggest the opposite.

Aims and objectives

This study is a first step towards answering the overall thesis question of how control processes contribute, positively or negatively, to children's creativity, by looking at trends in base correlation patterns between the constructs and their developmental trajectories across the primary school years. Some specific questions it will seek to address are:

- What are the patterns of correlation between sub measures, within and between divergent thinking tests, and within and between verbal and figural domains?

- Are there significant correlations between EC components and creativity sub measures? (this will involve both planned comparisons, based on the hypotheses above, and exploratory comparisons, using Bonferroni corrections)
- What are the similarities and differences in the developmental trajectories of EC and creativity components?

Methods

Ethics

The study was given ethical approval by the Departmental Ethics Committee of Birkbeck's Department of Psychological Sciences, reference number 161744. Safeguarding procedures were carried out in accordance with Birkbeck and Centre for Brain and Cognitive Development policy documents and online advice from the Care Quality Commission and the National Society for the Prevention of Cruelty to Children. If children became upset or did not want to continue with a particular test for any reason, they were allowed to stop immediately without question.

Power analysis

This study had an opportunistic element, since it involved participants at voluntary public outreach events, and it was not known in advance what the numbers and demographics of participants would be. Power analysis (Cohen, 1992) was carried out using G*power 3.1 (Faul et al., 2007). The main analysis of interest here was the correlation between EC and creativity measures, effects for which there are no well-established benchmarks of expected size in children. A medium effect size (at 80% power and a probability level of .05) of .3 correlation would need a sample of 84 for reliable detection (low correlation, e.g., .1, would require a sample size of 782; high correlation e.g., .5 would require 29). In practice, given the guidance limiting safe attendance and logistical constraints such as the time taken for testing and breaks, the number of participants was limited to 49. Given this, the study was statistically somewhat under-powered, and results should be considered with that in mind.

Participants and recruitment

Forty-nine primary school children were tested at university outreach events held over several days in two half term holidays. Children were recruited through flyers given to schools, nurseries, play centres and local public spaces (a sample flyer is included in the Appendix). Participants spent a half day at the university engaged in group-based, brain-related pedagogical activities, as well as taking part individually in research. Data were collected by a team of researchers; I collected all the creativity data; a fellow researcher collected all the EC data and research assistants collected cognitive ability data. The whole event was carried out in a fun, playful manner, to ensure children were at ease and to create as un-test-like an environment as possible.

Four children had incomplete tests and were excluded from the analysis. The final sample was 45 children, aged between 4.95 and 11.36 years (M = 7.97; SD = 1.82); 24 were girls. The numbers in each age group are shown below.

Age (years)	Number in sample
4	1
5	8
6	7
7	7

8	7
9	7
10	7
11	1

Table 2. 1 Age breakdown of children in the sample

Written consent was given by the child's parent/guardian and verbal consent was also sought from the child, after fully explaining each procedure, at each of the testing sessions.

Design and procedure

The design was cross sectional, involving children across the primary school age range.

Children were tested individually in labs at Birkbeck's Psychological Sciences department in half hour sessions – one each for creativity tests, EC tests and cognitive ability tests. In the creativity tests, particular emphasis was put, through the instructions and demeanour of the researcher, on playfulness – the games were just for fun, had no right answers and no emphasis was given to time limits. For the verbal tests, children answered out loud with the researcher recording their responses (so that writing ability/speed was not an impediment). If a child stopped responding, they were given non-specific prompts or encouragement ('You're doing really well', 'Good job, keep going'). If, after three separate prompts, they still said they had no more ideas, the test would be ended.

Between testing sessions, children participated in semi-structured crafts and games designed to learn about the brain e.g., making a papier-maché brain or neural networks from pipe cleaners.

Materials

Creativity tests

The Alternative Uses Test (AUT, Guilford, 1967a) requires participants to generate as many 'interesting and unusual' uses for an everyday object within a time limit. Children were given 3 minutes to respond. Answers were scored for fluency (total number of answers), flexibility (total number of categories) and originality. As we have discussed, there is ongoing debate about the optimal method for scoring originality (Forthmann et al., 2020a, 2020b; Plucker et al., 2014; Reiter-Palmon et al., 2019). Here, originality per response was scored by four independent raters, instructed to score each answer on a scale of 1 (not creative) to 5 (highly creative), taking into account their 'sense of the originality and inventiveness of each response, in one holistic measure'. Participant scores were calculated as the mean response originality score (i.e., total originality divided by fluency). Given the extent to which findings can be influenced by scoring choices (Forthmann et al., 2018, 2020a), an alternative, statistically based method calculating the rarity of responses within the sample was also used for comparison.

The Torrance Tests of Creative Thinking (TTCT, Torrance, 1974, 2016) are comprised of several tests in verbal and figurative domains. The verbal test used in the current studies was the 'Just suppose' test of divergent thinking ability, which requires the child to initiate creative thought from an imaginary situation (e.g., 'Imagine that clouds have strings attached to them which come all the way down to the ground'). As with the AUT, fluency, flexibility and originality are scored, this time according to the TTCT manual. Fluency and flexibility are scored as before but here originality is scored according to an in/out system; each response not listed in the manual's list of common responses receives 1 point for originality and score per child is the sum of response scores. Children had 5 minutes to complete each test in the TTCT.

The only exclusions for fluency were responses which repeated the instruction wording (e.g., giving the response ‘writing’ after the instruction, ‘A pencil is usually used for writing or drawing’). Inter-rater reliability (IRR) for fluency, calculated on 25% of the sample, was $\alpha=1$ for AUT and $\alpha=.99$ for Just Suppose. Inter-rater agreement for flexibility, defined as a ‘change or shift in attitude or focus’, was reasonably high ($\alpha = .89$ for ‘strings’, $\alpha = .69$ for ‘fog’). Originality for the AUT was rated by four blind raters (two researchers involved in the study and two external raters). Raters were asked to ‘take into account their sense of originality and inventiveness of each response, in one holistic measure’ and score each answer on a scale from 1 (not at all creative) to 5 (highly creative). The score awarded was the mean of the four raters. Interrater reliability was high ($\alpha = .80$ for ‘pencil’, $\alpha = .82$ for ‘bottle’).

The TTCT figural tests are simple paper and pencil drawing games in which children complete drawings around a range of starting stimuli (sample tests are included in the Appendix). The tests were scored according to the TTCT manual instructions, for fluency (number of completed pictures), originality (number of completed pictures not on the list of exclusions for common responses), elaboration (number of details added to picture) and overall creative strengths - specific bonus points for signs of creativity in 13 categories (emotional expressiveness, storytelling articulateness, movement or action, expressiveness of titles, synthesis of incomplete figures, synthesis of lines or circles, unusual visualisation, internal visualisation, extending or breaking boundaries, humour, richness of imagery, colourfulness of imagery and fantasy). Given the specific nature of the scoring instructions in the manual, figural tests were scored by just one researcher.

Description of EC measures

Tests of inhibitory control

Animal size Stroop

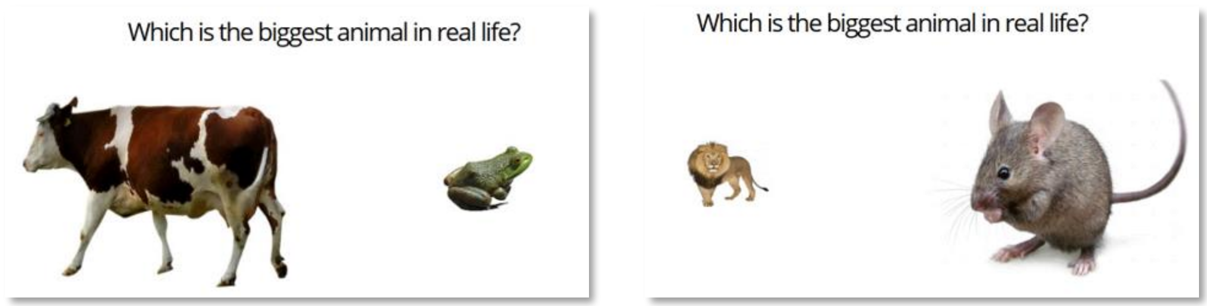


Fig. 2. 1 Examples of Animal Size Stroop trials, congruent (left) and incongruent (right)

A child-friendly version of the original Stroop test (Catale & Meulemans, 2009; Morris, 2020; Stroop, 1935) programmed in Matlab 9.1.0, was used. The design was based on Merkley et al. (2016). Children were presented with two animal pictures, one large, one small, on a screen. They had to decide which animal is larger in real life, irrespective of picture size. This meant that they had to inhibit the perceptual characteristics of the stimulus itself and answer in terms of their knowledge of the animals' real relative sizes. This inhibition is more difficult (that is, takes longer) when the relative sizes of the animals are incongruent (e.g., the lion image is smaller than the ladybird). Children responded by pressing a key on the keyboard (marked with a coloured sticker, to avoid inaccurate presses and children having to remember which letter) on the left or right side, corresponding to the large animal. The stimuli were photographs of animals on a white background; the large animals were lion, horse, cow, and elephant; the small animals were mouse, frog, rabbit, and ladybird. Large images were 72mm x 54mm in size; small images were 29 mm x 21 mm. Each trial lasted a maximum of 3 seconds, after which an error was recorded, and the next trial presented. Fixation times between trials varied between 600 and 1400ms to deter anticipatory or automatic responses. The images were presented in pairs on a computer screen at a distance of 50cm, in a quiet room away from the main activities. Children were asked to try and respond as quickly as they could while trying to answer correctly. Reaction times and accuracy were recorded.

Simple Flanker

Fig. 2. 2 Examples of Simple Flanker trials, congruent (left) and incongruent (right)

The Flanker is a test of selective attention (Eriksen, 1995), in which respondents must press a key corresponding to the direction of a central arrow (Rueda et al., 2004); here the version used, based on Anwyl-Irvine et al. (2020a) was programmed in Gorilla (https://gorilla.sc/) and used brightly coloured fish as the stimuli instead of the usual arrows. Children were presented with a horizontal row of fish in the middle of the screen, see Fig. 2.2; they had to decide which way the central fish was swimming (left or right) and respond with a corresponding left or right key press (as in the Stroop above). Sometimes the central fish is surrounded by fish swimming in the same direction (congruent condition), sometimes the surrounding fish are swimming in the opposite direction (incongruent condition). Research with this paradigm has consistently shown that reaction times in congruent trials are quicker than in incongruent trials; this additional time taken to distinguish target from distractors is often referred to as ‘conflict resolution’ posited to be carried out by the ‘conflict (Anwyl-Irvine et al., 2020a; Eriksen, 1995; Massonnié, 2020; Rueda et al., 2004).

As with the Stroop, fixation times between trials varied randomly between 600 and 1400ms. For each trial, a fixation cross was displayed for 1700ms followed by the screen showing the fish, which remained on screen until a response was recorded. There were 12 practice trials, where children received immediate feedback, followed by four blocks of 24 trials each, with a pause between blocks; children pressed a key when they were ready to continue. 50% of trials were congruent, 50% incongruent and trials randomised the direction in which the central fish was swimming. Again, children were asked to respond as quickly and accurately as possible. Accuracy (proportion of correct trials) and reaction times (RTs) for correct responses were recorded.

Working memory

Verbal working memory

This was tested with a backwards digit span task (St Clair-Thompson & Gathercole, 2006). Children were seated facing the researcher and had to repeat out loud, in reverse order, a list of numerical digits said out loud by the researcher. List length began with two digits and there were four trials at each list-length level. Children had to answer correctly on three or more trials to move on to the next level, in which list length increased by one digit. They kept going until they failed at two or more trials in a level. The total number of correct trials was recorded.

Visuospatial working memory

Children's visuospatial working memory ability was assessed using a child-friendly, computerised variant (Morris, 2020) of the Corsi block task (Corsi, 1972). The design was similar to that used by Morales et al. (2013) though here a reverse recall was used. Participants, as before, were seated 50cm from a computer screen in a quiet room. They watched a frog make a series of jumps on a 3x3 grid of nine lily-pads (see Figure 2.3) and were instructed to click on

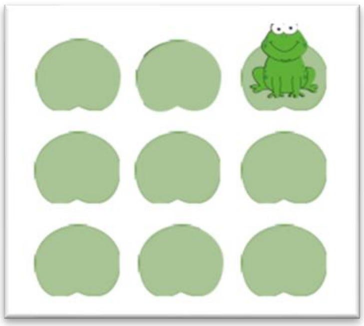


Fig. 2. 3 Example stimulus for visuospatial working memory (VSWM) Corsi block task

the lily-pads in reverse order, using the computer mouse, to indicate the lily pads where the frog had jumped. Children had up to 5 practice trials, with a sequence of 2 jumps, to make sure they understood the task, before moving on to the test trials. Test trials began with a sequence length of 2, with 4 trials at each level. Children progressed to the next level, in which the sequence length increased by 1 jump, if they answered at least 3 from the previous block correctly. They continued until they made 2 or more mistakes at any level. The total number of correct sequences was scored.

Flexibility (switching)

A test for switching was introduced only after the first outreach event. Based on a child-friendly version of the Wisconsin Dimensional Card Sort (Berg, 1948), children are shown two bivalent target cards (i.e., two colour types, two shape types), then must sort a newly presented card according to changing rules of colour and shape (Zelazo, 2006; Diamond & Kirkham, 2005). Since less than half the sample completed this test, it is not included in further analysis.

Standardised tests of cognitive ability

A verbal and a non-verbal measure of ability was assessed, primarily to benchmark the sample for cognitive ability across the age range. Both tests were assessed according to manual guidelines.

Fig. 2. 4 Illustration of the British Picture Vocabulary Scale (BPVS-III)

The British Picture Vocabulary Scale version 3 (BPVS-III) (Dunn et al., 1997), a test of receptive vocabulary, requires the child to choose which of four pictures corresponds to a word read aloud by the researcher. The words get progressively more challenging and testing stops when the child makes 8 errors within any block. Raw scores were recorded. BPVS-III norms for children 3-16 have a reliability of .91 (Dockrell & Marshall, 2015).

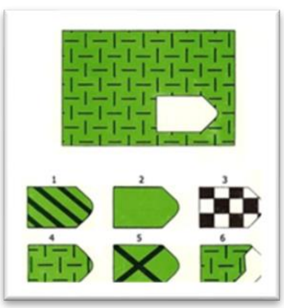


Fig. 2. 5 Illustration of a Raven's progressive matrices task

Non-verbal abilities were measured using Raven's progressive matrices **(**Raven, 2000) which require the child to select from a range of missing elements in an abstract pattern series. The test has split-half reliability of r = .85 for 5-8year old children (Carlson & Jensen, 1981). Raw scores were recorded.

Results

The results will be broken down into sub-sections. Firstly, the general cognitive ability data will be considered, by way of benchmarking the sample, since the tests used have norm scores and established developmental trajectories. Next, the constructs of creativity and EC will be considered separately, by examining consistency across different tests within each. Then development of creativity and EC will be considered, again separately, looking at the pattern of change across the age range. Finally, the relationship between creativity and EC will be examined.

General cognitive ability

The descriptive statistics for scores on the BPVS and Ravens are shown. Expected norm scores and their ranges for both tests are given on the basis of our sample's mean age of 7.97 years.

	Mean	*Norm score mean (75% CIs)*	SD	Min	Max
BPVS	114.44	*108 (85, 115)*	26.03	29	157
Ravens	27.63	*25 (17, 33)*	6.16	12	34

Table 2. 2 Means, SDs and range of scores on BPVS and Ravens (raw scores) and norm equivalents

Simple regression analyses were carried out to test whether, as expected, age predicted outcomes on each of these cognitive ability measures. Results clearly showed that it did for both.

	B	SE(b)	β	F(1,44)	p	R^2
BPVS	10.54 (7.52, 13.55)	1.49	.74	49.75	<.001	.55
Raven's	2.40 (1.65, 3.14)	3.04	.71	42.36	<.001	.51

Table 2. 3 Simple regression analyses of age on each measure of cognitive ability

Constructs of creativity and EC

Creativity tests

Verbal creativity results pre-processing

Since verbal creativity test data were also being collected for another study (looking at the effect of noise on verbal divergent thinking; Massonnié et al., 2019), each test was carried out in silence and in noise, with items counterbalanced. For the current analysis, only silence scores were used. To check there was no difference between items (i.e., between bottle and pencil for the AUT and between clouds and fog for Just Suppose) in any of the sub scores, independent samples T-tests were carried out. There was no significant difference between any of the sub scores. AUT fluency $t(44)=1.43$, $p=.160$; AUT flexibility $t(44)=0.64$, $p=.530$; AUT originality $t(44)=0.69$, $p=.491$; JS fluency $t(44)=0.77$, $p=.443$; JS flexibility $t(44)=0.51$, $p=.625$; JS originality $t(44)=1.26$, $p=.217$.

AUT results

All children came up with at least two ideas for alternative uses for everyday objects. There was wide variation in scores, particularly in fluency and flexibility, whereas originality scores were constrained by the method of scoring. An example of an answer scoring highly for originality for bottle was ‘use it as a stress ball’; a low scoring example was ‘flip it’. For pencil, a high scoring

	Mean	SD	Min	Max
Fluency	8.61	4.32	2	21
Flexibility	6.87	3.46	0	17
Originality	2.72	0.63	1	4

Table 2. 4 Means, SDs and range of scores in AUT

example was ‘eat it if you’re dying of starvation’; a low scoring one was ‘poke holes in paper’. There was a very high level of correlation between fluency and flexibility r=.92, p<.001 while correlations with originality were lower and not significant: fluency/originality r=.12, p=.431, flexibility/originality r=.25, p=.092.

Just suppose results

	Mean	SD	Min	Max
Fluency	11.13	6.37	1	34
Flexibility	4.17	3.27	0	16
Originality	8.61	5.72	0	29

Table 2. 5 Means, SDs, and range of scores in Just Suppose test

There was wide variation in performance for all sub measures but a very high level of correlation between them. Pearson’s correlations were: fluency/flexibility r=.82, p<.001, fluency/originality r=.95, p<.001 and flexibility/originality r=.84, p<.001. These highly correlated results made attempts to distinguish and interpret differences between fluency and originality more challenging. An example of a response receiving an originality point for ‘clouds’ was ‘You could make hammocks between the clouds’; one not receiving one was ‘Planes would get tangled up in the clouds.’

Correlations between the verbal creativity tests

The two verbal creativity tests have different starting points – one stimulus is a concrete object while the other is an imagined situation. The following correlations give a sense of whether, despite these differences, the sub measures are tapping similar constructs in the two tests. The correlational evidence suggests some solidity in the constructs of fluency and flexibility while the cross-test originality scores show a much weaker relationship.

	JS flu	JS flex	JS orig
AUT flu	.57**	.66**	.59**
	<.001	<.001	<.001
AUT flex	.66**	.75**	.66**
	<.001	<.001	<.001
AUT orig	.26	.22	.25
	.080	.150	.090

Table 2. 6 Correlations between sub measures across the two verbal creativity tests (Pearson's r and corresponding probability estimates)

Figural creativity results

All children completed two out of three possible figural tests, with each being scored for fluency, originality, and elaboration. Total scores were simple sum scores from the two tests. In addition, the children's total figural output (i.e., all their drawings together) was assessed for creative strengths, as previously described and according to the Torrance guidelines, to produce a 'creative strength' score.

	Mean	SD	Min	Max
Fluency	5.48	1.68	2	12
Originality	4.28	1.87	1	11
Elaboration	5.43	2.33	2	11
Creative strength	2.78	2.19	0	9

Table 2. 7 Means, SDs and range of scores in TTCT figural tests

Correlations between sub measures showed inconsistent relations. Some significant correlations are likely a by-product of scoring: for example, awarding strength scores (for various types of expressiveness) generally requires there to be a certain amount of detail in drawings, explaining the strong correlation with elaboration.

	Figural Fluency	Figural originality	Figural elaboration	Figural creative strength
Figural fluency		.62**	.21	.25
		<.001	.158	.091
Figural originality			.31*	.23
			.038	.120
Figural elaboration				.65**
				<.001

Table 2. 8 Pearson's correlation coefficient and related significance levels for TTCT figural sub measures

Creativity as a construct: correlations between different domains

We next turn to a comparison of scores between the verbal and figural domain, to better understand the degree of domain generality of creativity in our sample. Again, the picture is mixed. Some sub measures are highly correlated across domains (e.g., figural elaboration with most verbal measures) while others appear quite separate; neither fluency nor originality in the figural domain is significantly related to its counterpart – or indeed any other sub measure - in the verbal tests.

	Verbal tests				
	AUT Fluency	AUT originality	JS fluency	JS flexibility	JS originality
Figural fluency	.11	-.01	.18	.18	.13
	.472	.972	.235	.225	.387
Figural originality	-.03	-.08	.12	-.02	.08
	.872	.606	.427	.919	.601
Figural elaboration	.24	.41**	.29	.31*	.26
	.109	<.001	.051	.036	.078
Figural creative strength	.36*	.11	.30*	.29*	.28
	.014	.472	.045	.047	.057

Table 2. 9 Correlations between sub measures across verbal and figural domains. Pearson’s r and corresponding significance levels

Executive Control

Working memory

Results for the two measures of working memory (visuospatial and verbal) are shown. Correlations between the two measures were significant and moderately high: Pearson’s r=.41, p<.001.

	Mean	SD	Min	Max
VSWM	7.32	4.39	0	15
VWM	8.24	2.85	0	13

Table 2. 10 Means, SDs and range of scores for visuospatial and verbal working memory

Inhibitory control

Pre-processing of inhibitory control measures

Accuracy was at ceiling (>92% for congruent and incongruent trials) for both the Flanker and Stroop tasks so reaction times (RTs) for correct answers were used as the main measure for both tests. RTs shorter than 200ms were excluded as probable anticipatory reactions, being shorter than considered possible for the perception of the stimulus and generation of a response (Anwyl-Irvine, 2020a; Whelan, 2008). RTs more than three standard deviations from the mean for each participant were also excluded so that extreme values did not affect results (Anwyl-Irvine, 2020a; Whelan, 2008).

There are different approaches in the use of RT measures to represent inhibitory control. For example, some researchers (Hobbiss, 2019; Levy et al., 2018) have found that the degree of individual RT variability is the best predictor of self-reported distraction in children. For current purposes, the traditional measure of ‘Stroop cost’ and ‘Flanker effect’ i.e., the difference in RT between incongruent and congruent trials, was used.

Analyses of variance, with congruency as a within-subject factor, were carried out. For the Flanker task, RTs were significantly longer for incongruent (M = 941ms) than congruent (M = 897ms) trials ($F(1, 40) = 12.36$, $p = .001$, $\eta^2_p = .24$). For the Stroop task, RTs were also longer for incongruent (M = 1048ms) than congruent (M = 968ms) trials ($F(1, 40) = 38.45$, $p < .001$, $\eta^2_p = .50$).

For each participant, an RT cost score was calculated as the mean RT for correct incongruent trials minus the mean RT for correct congruent trials. Higher scores thus represent poorer inhibitory control (i.e., a relatively longer time is taken to overcome the prepotent sensory response in incongruent trials).

	Mean	SD	Min	Max
Stroop RT diff	75	90	-136	290
Flanker RT diff	43	79	-50	352

Table 2. 11 Means, SDs and range of scores (ms) for inhibitory control tests

Pearson's correlations were used to look at the relationship within and between measures of the two EC factors of inhibitory control and working memory. Results showed that tests within the same factor showed significant correlations while those between factors did not. The negative direction of correlations between WM and IC measures is to be expected given that high WM and low IC scores both represent better performance.

	VSWM	VWM	Stroop	Flanker
VSWM		.41*	-.15	-.24
		.012	.375	.162
VWM			-.26	-.24
			.089	.126
Stroop RT diff				.31*
				.050

Table 2. 12 Pearson's correlations and significance values for EC tests

Development: How do scores change with age?

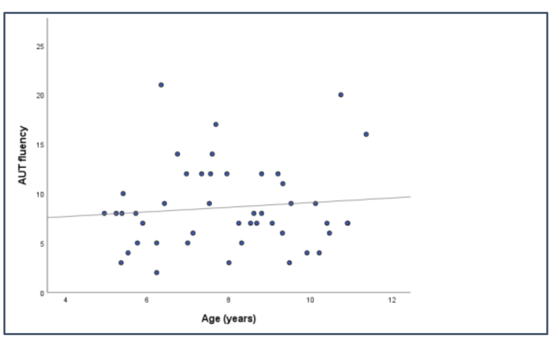
Creativity

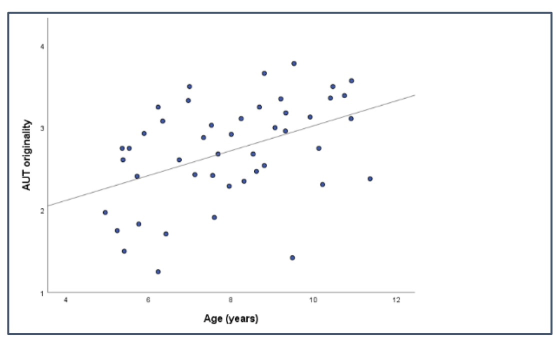
After carrying out checks for normality and examining scatterplots, to check that relationships were not best fit by non-linear functions, simple linear regressions were carried out to test whether age significantly predicted scores on each sub measure of both verbal and figural creativity tests. Results for each of the creativity measures are shown below, in Table 2.13 and Fig. 2.6.

	B (95% CI)	SE(b)	β	F(1,44)	p	R^2
AUT fluency	0.24 (-0.48, 0.95)	0.36	.10	0.44	.512	.01
AUT flexibility	0.48 (-0.08, 1.04)	0.28	.25	3.01	.090	.06
AUT originality	0.15 (0.06, 0.25)	0.05	.44	10.56	.002	.19
JS fluency	0.97 (-0.05, 1.99)	0.51	.28	3.65	.063	.06
JS flexibility	0.56 (0.04, 1.08)	0.26	.31	4.66	.036	.10
JS originality	0.75 (-0.17, 1.68)	0.46	.24	2.68	.109	.06
Fig fluency	0.12 (-0.16, 0.40)	0.14	.13	0.75	.392	.02
Fig originality	0.15 (-0.16, 0.46)	0.15	.14	0.94	.339	.02
Fig elaboration	0.43 (0.06, 0.80)	0.18	.34	5.54	.023	.11
Fig creative strength	-0.06 (-0.43, 0.30)	1.48	-.05	0.11	.737	.00

Table 2. 13 Simple regression analyses examining age (in years) as a predictor of each creativity variable.

It is notable that AUT originality showed the clearest age-related improvement and was the only measure scored subjectively by external raters. As we have discussed previously, originality can be scored in terms of objective, statistical rarity or subjective rater scoring, with much debate as to best approaches. Further exploration of the effect of scoring method on AUT originality scores





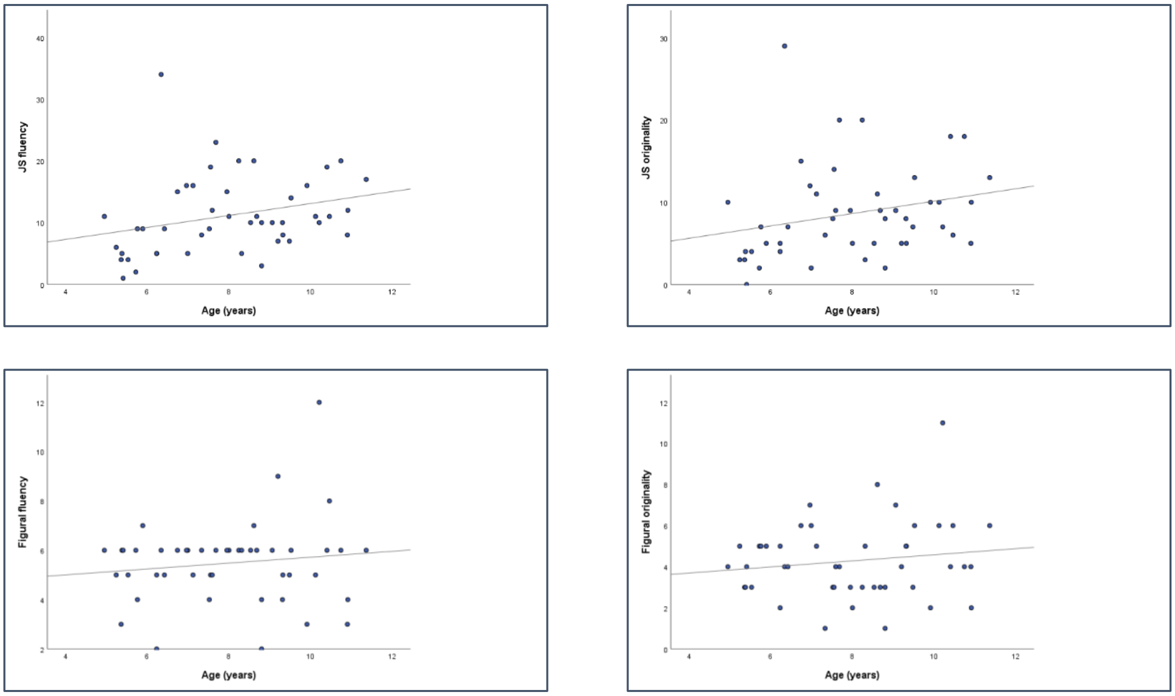


Fig. 2. 6 Scatterplots showing fluency (left) and originality (right) scores plotted against age, for AUT (top), JS (middle) and figural tests (bottom)

was carried out. Following the first round of data collection (i.e., after the first outreach event) participating children (n=28) were also scored according to the frequency method i.e., through statistical frequency of responses. The sample size for frequency scoring should ideally be a lot bigger (100 or more is typical), to provide a sufficient number of responses to differentiate statistical rarity; the small numbers here mean the following was purely exploratory. Correlational analyses between the two different measures of originality found that they were not significantly correlated (r=.34, p=.073) using Pearson's correlations, but non-parametric correlation (using Spearman's) suggested that they were (r=.42, p=.027). A simple linear regression looking at whether age significantly predicted AUT originality scored by the frequency method found that, unlike with the rater scoring, it did not (b=0.19 (-0.58, 0.97), SE(b)=0.38, β=.10, F(1,26)=0.27, p=.608, R^2=.01). The implications of this will be addressed in the discussion.

The other robust improvement over the age range was in figural elaboration, largely a measure of the amount of detail in drawings, an indicator of expected age-related progress. Flexibility in the JS test also showed significant improvement with age.

EC

Simple linear regressions sought to ascertain whether age significantly predicted scores for working memory and inhibitory control. Three of the four EC measures showed significant improvements with age. Performance on the Flanker did not significantly improve with age.

	B	SE(b)	β	F(1,44)	p	R^2
Verbal WM	0.87 (0.47, 1.27)	0.20	.56	19.67	<.001	.31
Visuospatial WM	1.42 (0.74, 2.10)	0.33	.58	18.11	<.001	.34
Flanker	-9.59 (-23.00, 3.82)	6.64	-.22	2.09	.156	.05
Stroop	-16.58 (-31.68, -1.48)	7.48	-.33	4.91	.032	.11

Table 2. 14 Simple linear regressions testing age prediction on each EC measure

Relationship between EC and creativity measures

The final step of the analysis was to consider the relationship between each EC and each creativity variable, controlling for age. Given the large number of variables considered, caution is advisable in interpreting findings - as with any case of exploratory study of multiple comparisons.

Working memory and creativity

Only AUT originality showed significant correlation with both WM tests. JS measures were piecemeal. None of the figural test sub measures showed significant correlations with WM.

	AUT			JS			Figural			
	flu	flex	orig	flu	flex	orig	flu	orig	elab	strngth
VSWM	.16	.11	.23	.30	.06	.28	-.06	.10	.05	.29
	.359	.514	.174	.078	.730	.097	.693	.566	.787	.091
VWM	-.12	-.10	.36*	.15	.10	.11	-.06	-.42*	-.19	-.32
	.488	.558	.030	.376	.572	.532	.706	.011	.279	.058

Table 2. 15 Correlations between working memory and creativity measures. Pearson's r and significance values, n=46

Inhibitory control and creativity

	AUT			JS			Figural			
	flu	flex	orig	flu	flex	orig	flu	orig	elab	strngth
Flanker	-.22	-.16	-.26	-.05	-.02	-.01	.04	.33*	.07	.03
	.177	.309	.096	.781	.904	.972	.813	.036	.666	.875
Stroop	.12	.10	.14	.03	-.05	-.03	.11	.23	.07	.00
	.451	.522	.395	.838	.762	.849	.514	.157	.687	.994

Table 2. 16 Correlations between inhibitory control and creativity measures. Pearson's r and significant values, n=46

The general picture was a lack of significant correlations between both inhibitory control measures and all creativity sub measures, both verbal and figural. The only exception was a significant moderate correlation between Flanker and figural originality.

Discussion

This study sought to better understand how EC and creativity are related, by examining correlations between components of each, in a cross-sectional study of 4-11year old children. The preliminary step was to investigate whether there were clear relationships at this componential level which would point to directions for more fine-grained investigation. Clear relationships, however, did not emerge. After using cognitive ability measures to validate the sample as typical for the age range, the constructs of EC and creativity were first examined separately. The EC measures showed strong correlations between different tests of the same construct (IC, WM) but no significant correlations between them. Performance on 3 out of 4 EC tests improved significantly with age. The creativity measures presented as more of a mosaic: there were inconsistencies in patterns of correlation between constructs (e.g., originality) and between tests both in the same (verbal) and in different domains. The majority of creativity measures did not show age related improvement. The mixed nature of the results for different sub measures meant that contemplating the relationship with EC raised questions of which scores to consider representative. From a theoretical point of view, it seems most reasonable to assume that a combination of noisiness of measures (particularly RT measures for EC and originality for creativity) and the small sample size are chiefly responsible for inconsistencies. In practice, the general pattern of correlations showed little discernible relationship between EC and creativity components. The exception was AUT originality which showed significant correlation with working memory. More detail and interrogation of these findings follows.

Benchmarking the sample

Performance on general cognitive ability tests served to validate the sample. Raw scores from both tests fell within the range set out by normed scores and, also in line with expectation, improved significantly with age. A further validation, more specifically of performance on the AUT, comes indirectly from a comparison of findings in this study with a recent study in adults, using a very similar testing protocol (Wang et al., 2017). Results were consistent across both studies, although children's scores in the present study were higher for both fluency and originality than their adult counterparts.

	Current study	Wang et al. (2017)
Sample size	45	35
Participants	Children 5-11	Adults (Chinese undergraduates)
AUT fluency	8.61 (2,21) (SD=4.32)	6.26 (2,12) (SD=2.97)
AUT originality	2.72 (SD=0.62)	2.04 (SD=0.23)

Table 2. 17 Comparison of results from current study with similar study in adults (Wang et al., 2017). Scores, range (where given) and standard deviations are shown.

Constructs of creativity and EC

The purpose of deconstructing the creativity measures was to establish the best sub measures for use in further, more detailed research and to explore, based on theory, differences in how sub measures relate to EC components. Two outcomes could have clarified next steps: high correlation between specific sub measures (e.g., consistency in 'originality' or 'fluency' in different tests) would have bolstered the notion that, despite scoring differences, the originality measure represents a common underlying process, whose relationship with EC could be explored and even experimentally manipulated. Alternatively, high correlation between sub measures would have suggested a lack of discriminability between underlying processes and measures could have been collapsed into a composite 'creativity' score, encompassing quantity and quality. In practice, neither scenario transpired. Most verbal measures did show high correlation but AUT originality did not, it stood alone – making it difficult to justify collapsing scores. But neither did originality scores show significant correlations across the different verbal tests, making it difficult to convincingly argue that it presented a process-consistent measure. Figural scores further complicated the picture. Elaboration served as a useful validation measure: older children are more dexterous, have more drawing experience, can work more quickly, and have a more developed sense of representational accuracy, all meaning age-related improvement would be expected (Kim, 2011) - and was seen here. Across domain, figural elaboration and AUT originality were the only measures which were significantly correlated – and which both showed clear age-related improvement. Within the figural domain, some correlations (or lack of them) can be explained by trade-offs – for instance, in a limited time, it might not be possible to produce both a large quantity of drawings and a high level of detail within them, explaining low correlation between elaboration and fluency. Similarly, it is hard to achieve scores for creative strengths without the elaboration needed to render a drawing humorous, emotional, or expressive, so correlations here were high. Fluency and originality are related partly as a consequence of the scoring method; originality scoring is by binary (i.e., a response either is or is not on the exclusion list) and an originality point can only be given to a drawing also scored for fluency, making certain results, such as high originality coupled with low fluency, impossible. It is also worth noting that, due to the large number of sub measures, multiple comparisons were made. If the data were nothing but noise, simple chance might lead us to expect to see some significant, but non-meaningful correlations.

Before we evaluate where this leaves us, let us turn to the more straightforward EC findings. Working memory measures showed good construct correlation and significant age-related improvement, as expected (Anderson, 2002; Diamond, 2013; Huizinga et al., 2006). The two inhibitory control tests were also significantly correlated, despite the fact they are tapping the different processes of selective attention (ignoring distractors) and cognitive inhibition (resolving internal conflict; Nigg, 2017), suggesting possible overlapping processes. The EC factors of WM and IC were not correlated in this sample, suggesting different mechanisms are in operation (Miyake et al., 2000).

Development of creativity and EC

Most measures we expected to see improve with age did: general cognitive ability, working memory and inhibitory control represented by the Stroop (Anderson, 2002; Diamond, 2013). Flanker did not improve with age. This finding was not completely unexpected given that others have found that IC shows less steady improvement with age (Huizinga et al., 2006; Lee et al., 2013) particularly when measured by RT difference (since these measures compound the noisiness inherent in RT measures; Draheim et al., 2019). The finding here is in line with another study which found no age differences in RT difference in a similar inhibition test with children aged 6-9 years (Rueda et al., 2004). Ceiling level accuracy meant that the test was not highly sensitive to improvements with increasing age, though the differences that were seen indicated an upward trend in performance.

Creativity improvements presented less clear age-related improvements. To some extent this was, again, not completely unexpected given evidence of turbulent progress (Barbot et al., 2016; Beghetto and Kaufman, 2014; Saggar et al., 2019). It was reassuring that measures known to show more consistent linear development with age, such as figural elaboration (Kim, 2011), did so here. The only other measure to show robust improvement with age was AUT originality. This exception will be explored below.

Why did so many of the sub measures not improve with age? Older children have more knowledge and experience, which should lead to greater fluency (Charles & Runco, 2001; Runco & Acar, 2010), but did not here, perhaps because they were more self-conscious about their ideas (Barbot et al., 2016) and self-edited. If so, did they conceive ideas and just not state them or did inhibition act earlier in the process? Their scores alone cannot tell us. It is also interesting that creative strength scores did not improve with age, despite the fact they were correlated with figural elaboration which did. Torrance himself (1974) emphasised the importance of the creative strength measure and expected it to improve with age, alongside better understanding of one's own and others' emotions.

Improved with age	No improvement	Borderline
AUT orig	AUT flu	JS flu
Fig elab	JS orig	AUT flex
VWM	Fig orig	JS flex
VSWM	Fig strength	
Stroop	Flanker	

Table 2. 18 Summary of age-related changes for creativity tests/sub measures and EC tests

Relationship between creativity and EC

The correlations between working memory and creativity measures were generally non-significant, with two exceptions: a significant positive association between AUT originality and verbal WM and a slightly larger (.42 vs. .36) negative one between Figural originality and verbal WM. This latter association might reflect the fact that working memory is less important in drawings since responses do not have to be kept in mind, but are offloaded to the environment (Barr et al., 2015) – although why this might only pertain to originality is unclear. Previous literature would lead us to expect that fluency would be the most likely beneficiary of better verbal WM (Benedek et al., 2014a; De Dreu et al., 2012; Zabelina et al., 2019). The association between AUT originality and verbal WM could be explained by the fact that, to produce original answers, one has to keep in mind obvious answers, previous answers and some estimation of the sort of answers likely to be given by others (Beaty et al., 2014; Benedek et al., 2014b; De Dreu et al., 2014; Nusbaum et al., 2014; Zabelina et al., 2019). Alternatively, the correlation could be related to improved verbal elaboration, with age as a mediating factor (Nusbaum & Silvia, 2011) and general knowledge and intelligence also playing a role (Benedek et al., 2014a; Kleibeuker et al., 2016; Lee & Therriault, 2013; Sternberg, 2006). Either explanation is imperfect in failing to explain why a similar relationship was not seen in the Just Suppose task, another test of verbal divergent thinking.

There were mostly no significant correlations between both tests of inhibitory control and creativity sub measures. The only exception was a moderate association between Flanker and figural originality. Given the lack of any theoretical underpinning for such a relationship, it seems likely a chance result from the multiple comparisons. The lack of consistent relationships, positive or negative, between inhibitory control and creativity measures made it difficult to get clues to resolve the conflicting evidence base (Edl et al., 2014; Mayseless et al., 2015b; Radel et al., 2015).

Indirect evidence regarding the relationship between creativity and EC comes from looking at their developmental trajectories. As we have seen, development of EC skills was shown, in 3 out of 4 tests, to improve steadily and significantly with age. The great majority of creativity sub measures did not show such improvement. If EC is an integral feature of creative thinking, this is an incongruous finding.

What have we learned? Conceptual and methodological considerations

Divergent thinking tests

With the experience of just one study, I can appreciate the debates that have raged about divergent thinking tests for more than half a century (Baer, 2011a, 2011b; Barbot et al., 2016; Cropley, 2000; Dietrich, 2007a, 2015; Kaufman, 2003; Kim, 2006, 2011, 2017; Plucker et al., 2011; Runco, 2008; Runco et al., 1987, 2010; Silvia et al., 2008; Simonton, 2000; Sternberg & Grigorenko, 2001; Torrance, 1972;). There is not space to go into all the intricacies. Instead, we will focus on three areas germane to this research since they affect what we are really interested in – namely, the creativity-relevant processes underlying test scores.

Scoring issues

AUT originality was the only verbal creativity measure which improved with age. Some argue that this is to be expected, since age-related gains in knowledge, intelligence and working memory will all contribute to greater originality (Beaty & Silvia, 2012; Benedek et al., 2014a; Nusbaum & Silvia, 2011; Sternberg, 2006). A problem with this argument is that it should equally apply to originality in the other verbal DT test – which showed no age-related improvement, and which was scored differently. AUT originality was the only measure subjectively scored by adult raters, something which could have affected outcomes (Runco, 2008). Exploration of the effect of a different scoring method, based on an objective measure of rarity of responses showed no improvement with age. Although this exploration was not statistically robust, it nonetheless points to the need to treat findings from subjective measures with an extra degree of caution (Forthmann et al., 2020a; Plucker et al., 2014; Reiter-Palmon et al., 2019; Runco, 2008). Do adult raters score older children's answers more highly because they are likely to be richer in detail (like figural elaboration, verbal elaboration improves with age;

Barbot et al., 2016)? Let's take an example: one child, aged 10, gave as an AUT response for a plastic water bottle, 'Dress it up as a Barbie and give it to your sister as a present.' For this response she scored 4.75, one of the highest scores in the sample. Another child, aged 7, gave the response 'Make a puppet', which scored 3, just over the sample mean. Both have reimagined the plastic bottle as a lifelike toy figure. Is there really a difference in the originality of their responses? Or is the difference primarily one of elaboration?

The problem here is the potential contamination of 'originality' (a sine qua non of creativity) with 'elaboration' (a contested component of it) and, more importantly for the current study, obfuscation of the true relationship of originality with EC components.

Instruction issues

For all DT tests, verbal and figural, children are given ambiguous instructions; the exact wording varies with task but consistently contains the idea of producing 'as many interesting and unusual ideas as' they can (Torrance, 1974; Wallach & Kogan, 1965). What is measured thus depends on how each child has chosen to interpret those instructions (Forthmann et al., 2016; Nusbaum et al., 2014). If they prioritise quality ('interesting and unusual'), there needs to be more evaluation of ideas, checking each against expectations of what constitutes usual and boring. If on the other hand, they prioritise quantity as the key determinant of success ('as many as you can') the focus is firmly on maximising generation of ideas, with less, if any, need for their evaluation. These decisions are likely to differentially evoke EC in their realisation.

The fluency/originality balance is of relevance not only to test scoring (Forthmann et al., 2016; Kim, 2006) but to creativity in the real world. While some see fluency and originality as antithetical, such that, in limited time, it is not possible to excel at both (Forthmann et al., 2016; Nusbaum et al., 2014), others, including many real-world creatives, suggest the optimal way to achieve originality is *via* fluency; historiometric studies have found high productivity to be a characteristic feature of highly creative people (Simonton, 1999) e.g., Emily Dickinson wrote 1800 poems in her lifetime but only published 10 (Emily Dickinson museum archive, 2018) and the twice Nobel winner, Linus Pauling, spelled it out, "The best way to have good ideas is to have lots of ideas and throw away the bad ones' (correspondence with David Harker, 1961).

Monolithic constructs

In this study, creativity and EC were deconstructed to look in more detail at relationships between specific aspects of each. This deconstruction could go further. For EC, we looked at WM and IC but as has been shown (Nigg, 2017), there are at least 8 different kinds of inhibition, each of which might affect creativity differently. By way of illustration, the table below (Table 2.19) uses responses given by children in this study to speculate about ways in which 'failures' of inhibitory control could have aided creative ideation.

For EC measures, it is conceptually possible to break them down and empirically assess the new, more clearly defined components, because there is at least a degree of clarity in what the components represent in terms of cognitive function. What about creativity? Are its sub measures (fluency, originality, etc.) any more than approximations of quantity and quality, of abstruse relevance to brain processes (Dietrich & Kanso, 2010)? We have seen from examples that underlying scores can be achieved via a number of different cognitive pathways. Even if one could break them down more, it is unclear how this would illuminate means rather than ends.

Type of inhibition	*How failure might facilitate ideation*	*Example (from AUT bottle)*
Motor	Embodiment might help ideation	'You could balance it on your shoe'
Selective attention	Distractions might spark ideas	'The noises helped me think of an instrument'
Behavioural inhibition	Emotional and physiological needs could be sources of ideas	'You could wee in it'
Social inhibition	Lack of social self-consciousness could mean expression of more ideas	'You could squash it in someone's face to annoy them'
Cognitive inhibition – proactive	Overly broad suppression could rule out fruitful sub-categories	'You could use it to water flowers'
Cognitive inhibition – retroactive	Previous ideas could lead to new ones	'Make a torch…Make a shadow'
Interference control	Over-blocking irrelevant items could rule out potential answers	'You could use it to make palm tree in a desert'
Oculomotor inhibition	Visual search could prompt ideas	'Use it to make a door handle'

Table 2. 19 How 'failures' of inhibitory control could theoretically lead to ideational success

Limitations

Much of the discussion has already been given over to limitations in this type of study. In addition, here, were the small number of participants covering a wide age range, the omission of a test for flexibility and several issues concerning time. These ranged from the difficulty of having to stop children mid-flow whilst also maintaining an un-test-like environment, through to having to prompt children repeatedly over the 5 minutes of a verbal test when it was clear their enthusiasm had diminished after just 1 or 2.

Conclusion and next steps

In summary, this study sought evidence of clear relationships between EC and creativity components. Largely, these relationships were not found and even when they were (e.g., a significant correlation between VWM and AUT originality) there were reasons for misgivings as to their veracity. The findings suggest DT tests must be used in a more targeted way to examine creativity and we propose two potentially fruitful ways forward. The first is to use these tests, not as the means to examine differences between individuals, but to examine within-individual change in performance over time. In Chapter 5, we will do this, by means of a school-based training intervention which will seek to improve EC and then consider concomitant effects on creativity. Test-retest reliability is reasonably high (between .50 and .93 for TTCT; Kim, 2006) and consistencies in creative approach are more likely within the same individual.

The second is more of a leap; children's responses in a DT test contain a great deal more than the substrate for a score, they contain detail and potentially useful 'thought probes' for information about the processes underlying their origination. So, the second approach to a potentially productive use of creativity tests is not to answer the question 'How creative is this child?' but to ask, '*How* is this child creative?' It is to this question that the following qualitative investigation will now turn.

Chapter 3. A qualitative analysis of how EC processes contribute to creativity in children aged 6 to 10

Introduction

In this section, I will briefly outline the need for qualitative work to fully confront the thesis topic, then focus more tightly on the reasoning behind the specific methodology used here. The broader issues, particularly regarding epistemological consistency, will be touched on, but these will be tackled more fully in the next chapter, when quantitative and qualitative findings come together. The methodology used here will be justified both from a theoretical position and a practical one, with reference to exploratory pilot studies. As regards the ongoing debate about the value of first-person reports in giving insight into cognitive processes, I will present the sceptical position, the refutations of others who reject its pessimistic conclusions and steps I have taken here to maximise the validity of verbal reports as a route to thought processes.

Why a qualitative study?

The previous chapter highlighted many well-known problems with quantitative lab tests for creativity (Forthmann et al., 2020a; Lubart & Besancon, 2017; Plucker et al., 2004; Reiter-Palmon et al., 2019; Runco & Charles, 1993; Runco, 2008; Silvia et al., 2008). These include issues caused by the test-like settings themselves, such as the difficulty producing creativity on demand and stress affecting creativity, time constraints, poor correlation between test items, lack of intrinsic motivation and an undue focus on divergent thinking. In addition, much good data from these tests are effectively wasted when interesting answers, potentially revealing of underlying mechanisms, are converted into binary scores. There are also problems, which have been previously discussed (Anderson, 2002; Cepeda et al., 2001; Luna et al., 2004; Wallisch et al., 2018) with lab tests of EC. These include there being many aspects to each EC factor but rarely time to test them all, ecological validity issues, poor correlations between test items and the conceptual problem of whether small, focused computer-based tasks (e.g., for ‘switching flexibility') are reliable guides to the broader implementation of control / switching which might be germane to our research questions.

The problems with creativity and EC measures become still more onerous when we consider the relationship between these constructs during the creative process. Their relationship is likely to be dynamic, altered by task factors, individual factors such as motivation and personality, and environmental context (Amabile & Pillemer, 2012; Amer et al., 2016; Barr et al., 2015; Ivancovsky et al., 2018; Pinho et al., 2016). Static behavioural tests are not equipped to capture this dynamism and complexity. Mapping test outcomes (measured as products) to processes depends on the ingredients of that process having been comprehensively charted, something which is distinctly not the case for the creative process in children.

The strength of qualitative research is in providing the tools to look at process. It can reflect the unfolding of a thought process over time, be it seconds, minutes, or hours. This contrasts with quantitative creativity studies, in which time is often seen as an irksome complicating factor. Qualitative analysis allows us to consider both micro and macro levels. We can consider details within a child's specific response to a specific question and we can analyse their entire set of responses, to interpret clues at a different level: did their approach vary at different times or in different contexts? While quantitative research can help us answer questions about what children did, qualitative can give us insight into how they did it. Exploiting the benefits of both approaches carries the potential advantage of convergent evidence from diverse sources, while simultaneously reducing the limitations inherent in any single method (Johnson et al., 2007).

Not everyone would agree with this position. Some suggest that the positivist, scientific approach which underlies much quantitative research is simply incompatible with the interpretive, constructivist approach characterising qualitative research (Yardley & Bishop, 2008). However, the distinction between qualitative and quantitative is far from black and white. Rather these are shorthand terms for a whole array of different methodologies and epistemologies (Midgley, 2006) with as much diversity within the categories as between them (Hammersley, 1996). This is particularly true for creativity research, where a 'pure' quantitative approach is unattainable: subjectivity and value judgements are, simply to judge what counts as creative, a definitional part of it. Throughout this thesis, my approach is one of pragmatism (Fishman, 1999; Johnson et al., 2007; Morgan, 2014; Yardley & Bishop, 2008), a methodological approach (discussed more fully in the next chapter) that aims to transcend the dualisms of subjectivity/objectivity, induction/deduction, and specificity/generalisability. As Morgan expresses it, "In a pragmatic approach, there is no problem with asserting both that there is a single 'real world' and that all individuals have their own unique interpretations of that world" (Morgan, 2014, p. 72). Every method conceals some things and reveals others (Yardley & Bishop, 2008) and we must only ask what we can learn from each (Eisner, 2003) and, as Saldana (2015) suggests, take as our starting point the best methods to research the questions we are interested in.

Children's verbal reports as data

Do children have the abilities necessary to report on their thought processes? A prerequisite for qualitative methodologies resting on verbal report is that the target is a deliberative phenomenon. Recent research has challenged the orthodoxy that metacognitive awareness emerges at 8-10 years (Whitebread et al., 2010), suggesting rather that children as young as 3-5 use self-regulation strategies (Whitebread et al., 2009). Verbal qualitative techniques have been shown to be an effective means, in terms of producing meaningful data, of assessing them in children of primary school age (Meier & Vogt, 2015; Morgan et al., 2007; Vandevelde et al., 2015).

Two qualitative techniques were piloted to evaluate their effectiveness in providing insight into children's thought processes as they created. The 'think aloud' protocol (Ward & Traweek, 1993) involves continuous out-loud verbal expression of thoughts concurrent with task completion (Sowden et al., 2020); it has been used previously in the assessment of creativity (Fleck & Weisberg, 2004; Gilhooly et al., 2007) and with children (Camp et al., 1977; Davey et al., 1993) though its use in young children is limited (Vandevelde et al., 2015).

The other method tested was stimulated recall (Bloom, 1953; Calderhead, 1981; Després, 2021; Lodge et al., 2000; Morgan et al., 2007). The method is underpinned by the idea that people can vividly relive a situation when they are presented with sufficient cues to the stimuli which characterised the original (Bloom, 1953); the technique often involves the use of audio or video recordings to aid recall (Després, 2021; Henderson & Tallman, 2006). It too has been successfully used in children (DeWitt & Osborne 2010; Järvelä & Volet, 2004; Lyle, 2003; Määttä & Järvelä, 2013; Meier & Vogt, 2015). Here, both the piece of work produced (e.g., a picture) and the video data served as stimuli for a semi-structured interview immediately after completion of the work.

The pilot work pointed to stimulated recall as the more effective tool for this study. While think aloud might be useful when studying clearly delineated activities (e.g., thinking aloud while solving arithmetic problems), in pilot studies here, children had great difficulty maintaining the sort of focus required for an open-ended creativity task while simultaneously reporting their thoughts. The effect was that the task itself took on different features (most noticeably, a reduction in productivity) compared to when no think aloud was involved. This is problematic because, as will be seen later, in Chapters 5-7, we will seek to compare findings from qualitative and quantitative data derived from the same tests. We wish to ensure that the processes evoked in the qualitative interviews are equivalent to those at work when tests are being used to generate quantitative findings – in short, to compare like with like.

Specific features of stimulated recall can help maximise its validity. Morgan and team used stimulated recall to study classroom learning in children aged 3 to 7. They recommend that interviews be conducted as soon as possible after the session (ideally within 48 hours), that only individuals rather than groups should be interviewed and that children be given some agency over playback (Morgan et al., 2007). Meier and Vogt (2015), who used a combination of inductive and deductive approaches for their analysis (a similar approach to the one that will be taken here) further emphasise that questions need to be authentic, with researchers genuinely open to any response; children must not be given the impression that any answer might be right or wrong.

Scepticism and refutation: can first person reports give insight into cognitive processes?

As indicated in the introductory chapter, discussion of the reliability of first-person reports as instruments for assessing cognitive processes has been a vexed one in psychology, and one we need to confront. Since Nisbett and Wilson's stark conclusion that 'There may be little or no direct introspective access to higher order cognitive processes' (1977, p. 231), many psychologists have written off introspective tools altogether. Is such pessimism justified?

Nisbett and Wilson's work is comprised of both a review of literature and their own large set of novel experiments. They begin by reviewing a hefty body of introspection-relevant evidence from diverse sources. These include cognitive dissonance studies (e.g., Zimbardo et al., 1966) in which participants must seek to justify acting on instructions to do essentially unpleasant things (such as administering electric shocks) and in so doing alter their explanations; they include complex psychosocial experiments (e.g., Goethals & Rechman, 1973) where participants are manipulated into dramatically changing their attitudes (in this case about whether children should be bused out of their locales for school in order to reduce racial segregation) but who then fail to acknowledge any attitude shift; and they include problem-solving experiments in which participants are given enormous clues to help them solve the problem (e.g., swinging a rope to give a clue how to solve Maier's two string problem) which they nearly all fail to acknowledge in their explanations of their success (Maier, 1931).

The validity of many of these experiments can be questioned on the basis of ethics, unfair manipulation, ego-involvement, pressures to abide by social norms and more - and a strength of this paper is that Nisbett and Wilson do precisely that, before proceeding to devise a raft of their own new experiments, free from all these problems, to prove the same point - that people's self-reports are demonstrably erroneous. Though perhaps theirs are not entirely problem-free; one experiment involved asking participants to explain their preferences for stockings and nightgowns in a lingerie department - an environment loaded with social unease. Others involved tapping into unconscious biases (which are often socially problematic to report) and most involve a high level of external manipulation. Most importantly though, all involve asking participants to report on the 'whys' rather than the 'hows' of their thinking – in other words, to justify rather than to describe. In their conclusions, Nisbett and Wilson state, "We also wish to acknowledge that the studies do not suffice to show that people *could never* be accurate about the processes involved. To do so would require ecologically meaningless but theoretically interesting procedures such as interrupting a process at the very moment it was occurring, alerting subjects to pay careful attention to their cognitive processes, coaching them in introspective procedures, and so on" (p. 246, italics in original).

Contemporary researchers have taken up the use of just such ‘theoretically interesting procedures’ and honed and developed tools to make meaningful use of introspective reports to study cognition (Braboszcz, 2012; Braboszcz & Delorm, 2012; Fazelpour & Thompson, 2015; Petitmengin, 2006; Petitmengin & Lachaux, 2013; Petitmengin et al., 2009, 2013). In a persuasive study, Petitmengin and colleagues (2013) reproduced protocols developed by Johansson and team (2005) which aimed to consolidate and build on the ideas of Nisbett and Wilson. Their (Johansson and team’s) study involved showing participants paired sets of pictures of women’s faces and asking them which one in each pair they found most attractive. In the protocol, participants are then reshown the picture and asked to explain the reasons for their choice - but in some cases, the picture they are shown for this explanation phase has been swapped i.e., it is in fact the face they did *not* choose. In 73% of cases, participants fail to spot the substitution and go on to give explanations based on the choice they did not make. The other 27% spot the substitution. Petitmengin’s team, using the same procedures and even the same set of pictures as Johansson et al., introduced a new condition in which an ‘elicitation interview’ was carried out between making the choice and being asked to explain it, for one of the participant groups. The rationale for the technique, according to the authors, is that “our natural tendency” when asked to describe a cognitive process, “is to slip surreptitiously from the description of our actual experience toward the verbalisation of justifications, beliefs, explanations, generalisations and abstract knowledge about our experience” (Petitmengin et al., 2013, p.656) but that this tendency can be avoided through detailed elicitation of the actual process. By using specific prompts and questions, participants can be guided to avoid generalities and stay focused on thoughts situated in a specific time and space. ‘Why?’ questions are avoided, with questioning instead along the lines, ‘When you see the pictures, what happens?...What happens after this?...When you look at the face on the right, what do you look at first?' and so on. In other words, it is firmly description rather than interpretation or justification which is sought. Applying this technique to the Johansson team's protocols, Petitmengin's team found that their control group (i.e., those without the elicitation interview) detected the manipulation at very similar rates to the original Johansson study, but with the elicitation interview, the detection rate was 80%.

The conclusion from this and other similar work is that, although our naïve descriptions of our decision making are often inaccurate, they can be improved with training: verbal reports can be informative if properly elicited. Indeed, similar work has been coupled with neuroimaging to gain insight into mental functions including consciousness in the field of neurophenomenology (Bagdasaryan, 2013; Fazelpour & Thompson, 2015; Lutz & Thompson, 2003; Varela, 1996). For the current work, there are some further points of relevance:

- some of the habits which can make reports inaccurate (i.e., sense of social norms and expectations) might be less developed – and so less of a problem - in children
- there is likely to be a difference between thought processes which involve EC (often deliberate, well explicated) and those which do not (more likely to be spontaneous, unconscious) in terms of their immediate accessibility to verbal report, something which can be exploited to aid differentiation between EC-dependent and EC-independent processes in the current work
- in the current research, children are spontaneously producing a new creative work, for which there is no prototype and no expectation, external or internal, so there is no obvious recourse to norms-based justifications

Aims and objectives

The primary aim of the study was to assess, using children's own descriptions, the extent and nature of involvement of executive control in their creative process. To be clear, even though this study developed from a perceived deficiency of divergent thinking tests, the goal here was to look more broadly at executive involvement in the full creative process, in a naturalistic setting, with a task that children were highly engaged in. The goal was not to assess EC involvement solely in DT tests but rather to avoid many of the shortcomings of lab-based studies through not imposing time limits, maximising motivation, and agency by allowing children to select the domain, materials, and stimuli and in having no judgement of the finished work. At the same time, it was important to ensure that the task met criteria for creativity by being novel (ensured by the use of the 'sparks' described below, which children had never seen before) and valuable (in meeting the goal of producing a piece of work according to the instructions).

The subsequent thematic analysis (Braun & Clarke, 2006) combined an exploratory approach, based on the fact that children's own accounts and experience is not currently well described in the literature, with a theoretical approach, based on the fact that certain features of the creative processes well documented in adults are likely also to occur in children. The analysis was, as counselled by Braun and Clarke, 'grounded in', yet 'going beyond' the data; that is, it was analysis rather than simple description. As far as I know, this is the first study which has used a stimulated recall technique to evoke children's accounts of their creative process.

Methods

Research design overview

Fourteen children were interviewed. The children, drawn from a larger sample who had already completed lab tests for creativity and EF (the ‘Bright Sparks’ sample presented in Chapter 2), chose whether to do a storytelling or a drawing activity and were given ‘sparks’ to ensure that their produced work was novel. They could complete their chosen creative activity with minimal rules and an explicit lack of time constraint and were videotaped doing it. Immediately afterwards, they were interviewed about their work, using both the playback of the video, the sparks and their picture or story as stimuli to prompt their recall of their thoughts at the time of execution. Interviews, which were audio-recorded, were subsequently transcribed and analysed within a theoretically grounded thematic analysis framework.

This task design was chosen to ensure both that children were well motivated for the task and that they had enough time to become immersed in it. The interview set-up was designed to strike a balance between not interfering during the creative process itself but minimising the time lag between engaging in the process and recalling the thoughts had while doing it. The choice of analysis was based on two main factors. Firstly, theoretical thematic analysis sought a balance between deduction from a robust theoretical foundation built on the adult evidence and induction based on an openness to the possibility that children might give accounts or insights not predicted by the adult literature. Secondly, given this study sits within a mixed methods approach, it was based on epistemological consistency across the qualitative and quantitative work – namely, a pragmatic approach which posits that access to reality is always mediated by analysis involving at least some degree of interpretation (Morgan, 2014).

Recruitment and participants

The children involved had all previously participated in the Bright Sparks event, at which parents had been asked whether they would like to be contacted about further research opportunities. All parents who had expressed an interest were contacted by email and further telephone conversations arranged with those who responded positively. During the phone calls, I talked through the study in terms of its purpose and logistics and gave parents the chance to raise any questions or concerns. Parents then discussed the study with their child and responded to say whether they would like to go ahead. In all but one case, children chose to be interviewed at home, at weekends or early evenings after school; the final child was interviewed in a room in the university since her parent worked nearby.

In total, fourteen children took part, 4 boys and 10 girls. The socioeconomic status of their families (as measured by maternal education) ranged from those who had left education after secondary school to those with post graduate level education (Hackman et al., 2015). They were all neurotypically developing and none had statements of educational need. Their age ranged from 6 to 10. Details are shown in Table 3.1.

Children were told at the point of commencing that the study was attempting to understand their creative process and that they were the experts, since only they knew what was in their heads. It was emphasised that there were no wrong answers. Efforts were taken to ensure that they felt not only comfortable but empowered, through giving them agency in choice of materials, domain, timing, and choice of location. The details of what would happen were carefully explained and time was given for children to ask any questions they had. Effort was taken to put children at their ease; this was made easier because we had met before at the Bright Sparks outreach event and they expressed positive memories of that experience. I took time to chat with them

Pseudonym	*Age*	*Gender*	*SES*	*Domain*
Ben 10	6	Boy	3	Drawing
Dave	6	Boy	5	Drawing
Snowy	7	Girl	5	Storytelling
Silky	7	Girl	3	Drawing
Dooda	7	Girl	NA	Drawing
Maria	8	Girl	5	Drawing
Lexy	8	Girl	1	Drawing
Harriet	9	Girl	5	Drawing
Imagination Creation	9	Boy	4	Storytelling
Alexandra	9	Girl	5	Drawing
Betty	9	Girl	3	Drawing
Alex	10	Boy	4	Drawing
Kitty	10	Girl	1	Drawing
Roxy	10	Girl	4	Drawing

Table 3. 1 Description of participants in qualitative study. SES measure based on maternal education scale 1 to 5. Pseudonyms were names chosen by the children to protect their identities.

beforehand and create a relaxed environment, for example by letting them play with the video camera and audio recorder and having them select and set out drawing materials etc. Parents or carers generally stayed in a neighbouring room or were doing chores around the house while the study took place so only myself and the child were present during both the drawing / storytelling and the subsequent interview. In one case, a parent asked to sit in during the interview stage, and in another, a child who spoke English as a second language called upon a parent to help with some tricky translation.

All the children were given a craft activity book as a thank you for taking part as well as a certificate; these were both given at the end of the session. In order to protect their identities, all children chose their own pseudonyms.

Ethics and data protection

Written consent was first sought from parents/guardians once they fully understood what was involved. On the day of testing, verbal consent was also sought from the children. They were reminded that they could stop at any time without having to give a reason.

All data were stored, in line with BPS guidelines and General Data Protection Regulations 2018, on an encrypted drive to which only I knew the password. Physical materials were kept in a locked filing cabinet to which only I had access. Data issues were fully discussed with parents/guardians.

The research received ethical approval from the Departmental Ethics Committee, Department of Psychological Sciences, Birkbeck College University of London, approval number 161762.

Testing protocol

The children were asked if they would prefer to do a storytelling or a drawing activity. For both, I told the children that I would like them to make something new and creative and that they would have as long as they wanted to work on it. I explained that to help them come up with ideas I had brought some idea ‘sparks.’ These were picture stimuli, selected based on their frequent appearance in children's stories, produced as colourful, visually appealing versions. The images are included in the Appendix. They were presented on small cards which the children could handle. The stimuli fell into four groups:

- *Places*: a castle, a house, a tepee, mountains
- *Animals*: a lion, a parrot, a frog, a camel
- *Objects*: a present, a candle, a crown, a cake
- *Imaginary characters*: a witch, a mermaid, an alien, a dragon

The children were presented with one group at a time and invited to choose one item from each, to make four items in all – a place, an animal, an object, and an imaginary character. For the storytelling activity, the sparks were fully recognisable pictures. For the drawing activity, they were evocative shapes (see Appendix) which might suggest the intended target (e.g., a lion) or something else and were chosen following earlier piloting (with a different group of children) using simple word equivalents of the pictures. The piloting showed up two problems: firstly, the children found the word cards less appealing and secondly the children became preoccupied with veracity of reproduction ("I won't choose that because I don't know how to draw a castle"). The use of the more enigmatic shapes got around both problems as well, as will be seen later, as providing some rich ground for studying divergent thinking.

In practice, the selection and choice of stimuli were not strict rules. In some cases, children wanted two from one set, or none from another and that was perfectly acceptable. I also explained that how they used the 'sparks' was entirely up to them – if the spark led to another thought, that was perfectly ok, that was why they were called 'sparks' – they might light up something else. Equally, if they wanted to use the sparks as they were, that was also totally acceptable. The primary guiding principle was to make sure that children were motivated. Secondarily, the sparks encouraged at least some degree of novelty (as opposed to the children recreating a story or drawing entirely from memory).

The children carried out their activity without any interruption from me and they told me when they had finished. Including the time taken to view and select ‘sparks’, the storytelling usually lasted for 15-20 minutes and the drawing for 30-45 minutes. Example stories and drawings are in the Appendix.

Data collection procedures

The first stage of data collection was making the video which would form the basis for the subsequent stimulated recall session. While the children were engaged in their creative activity, they were filmed on one camera for the storytelling or on two cameras if they chose to draw. For the drawing, one camera was positioned on a tripod capturing a shot wide enough to include both the child and their evolving picture (for future reference during the analysis phase). The second camera sought to reproduce as closely as possible the child’s own point of view (POV) while they were doing the drawing. This camera was usually handheld and positioned behind the child, to frame both their drawing hand and the wider canvas. It was this second camera which was used for the subsequent stimulated recall interview. In the case of storytelling, the camera was positioned as discretely as possible (to minimise children’s self-consciousness), close to me, on a mid-shot (head to waist level) to capture story narration and any gesticulations. This first stage of data collection was for the sole purpose of gathering the material on which to base the interview, which would then become the primary data source.

The second stage of data collection took the form of a semi-structured interview carried out immediately after completion of the creative work. The interview was audio-recorded on a small portable device. The POV video was replayed on a projector direct from the camera onto a wall (usually a source of great fascination) and children were encouraged to ask to stop at any point during the playback to talk about their thinking. I also stopped the tape to ask them questions. At other times, for example if there was a long period of colouring in, the video would continue running in the background alongside the interview. A core list of questions was asked of all participants; these are included in the Appendix; other questions were in reaction to specific responses from each child.

The emphasis in the questions was on process rather than explanation – 'How? What? When?' rather than 'Why?' questions. Children were guided not to focus on why they had made particular decisions or to justify anything that they had done, but rather to focus on the mechanics and dynamics of where particular thoughts came from, how one idea led on to another, the order in which things happened in their brains and so on. Except for one very quiet child, the children seemed to be enthusiastic, able, and willing to engage at this level and their descriptions were fluent and rich. Children seemed to enjoy the novelty of being asked this sort of detailed, process question; one child even remarking rather ruefully, 'Adults never usually ask this type of thing'.

The whole process, including production of the creative work and the interview took between 90 and 150 minutes, with 2 hours being the average length of time. Each child was seen on one occasion only. There was a short follow up, carried out by telephone or email, to reiterate thanks and occasionally check a detail such as a date of birth or the spelling of a pseudonym.

The primary data were the interview and its transcript. Secondary data included the creative work itself (i.e., the picture or story produced), the stimuli selected as 'sparks', the video of the child producing the work, field notes taken at the time (reflecting on contemporaneous observations and broader contextual cues such as the environment, noise and other distractions) and familiarisation notes taken at the time of producing the transcripts.

Analytical method

The analysis involved several stages which built up iteratively and recursively. The first stage involved listening back to the interview recordings three or four times before transcribing them in full. After each transcript was written, a familiarisation document recorded the most salient points arising from the interview, noted aspects hard to capture in words such as tone of voice or signs of fidgeting and gave a short account of first impressions. Transcripts were then printed, line-numbered and centred to leave space on each side for notetaking in the subsequent analysis. All analysis was initially done by hand (i.e., without qualitative analysis software tools). The following section describes the process in its entirety.

The first step was to read through the whole transcript. In some cases, several weeks had passed between interview and analysis. The first (left side) stage of analysis involved going through the whole script one line at a time, recording everything evoked by each line. Sometimes this was an interpretation of what the child meant, sometimes a question it prompted or a memory of what the child was doing at the time, or occasionally a comment about how a particular line might fit (or not) with other aspects of that child's account. This was an open, unfettered, comprehensive process, written in free-flowing prose, which was a useful way of corralling all the secondary data sources outlined above into the primary data as a record. This process could extend to several days' work for each interview.

The second (right side) analysis began with a clear focus on the research question: *How do control processes contribute, positively or negatively, to X's creativity?* Again, the process involved dissecting the script line by line, but this time with a spotlight on how the child's account revealed something about the influence of control processes. In this stage, unlike the first, there were sometimes passages where nothing was noted because nothing helped to answer the research question. The nature of the record here was a shorthand, a brief description of what a line conveyed; some researchers might refer to it as a 'code', but I prefer the term 'description', as less clinically cold.

I should report that this was not the way I initially intended to analyse data. I had spent some time before data collection developing an 'a priori' framework for coding (included in the Appendix). When analysing the data though, applying these codes felt more a rather coarse labelling exercise than an analysis. Moreover, starting with the children's actual words often better captured their experience of the process than a code. For example, several children referred to ideas 'popping up' or 'popping into' their heads, to describe the experience of having ideas appear spontaneously without deliberate effort, technique, or strategy. Using descriptions such as those, which served both to address the research question and to represent children's words more directly, gave a substrate for analysis with greater authenticity and depth.

The purpose of thematic analysis is to identify and understand recurrent patterns which occur across data sets – within an individual and between them. Here, the units of analysis were generally phrases though sometimes whole sentences and even whole transcripts were considered, since this analytical method allows 'zooming out' as well as 'zooming in'. For example, an account might, in one part of the interview, describe *high* involvement of control processes when planning what to do, but then, in another part of the interview, describe *low* involvement or even processes apparently exempt from control, for example while telling the story or drawing. In such instances, descriptions might emerge not from the child's words per se, but from a comparison of their accounts at different times. This is one way in which the dynamic nature of the relationship between control processes and creativity could be captured.

After completing all the descriptions and referring back to the secondary data sources and the ‘left side’ notes to ensure nothing had been omitted, they were transferred to an excel document, with the columns: page number, line number, description, and relevant quote from transcript. Quotes which were subject to more than one interpretive description were documented twice (this was a relatively rare occurrence). After repeated readings, descriptions were gradually brought together into themes of similar meaning.

The subsequent analytic stages involved a recursive shuttling between descriptions and themes, refining, renaming, and finessing themes and checking the best fit of descriptions within each theme. Theme descriptions developed over time, with balder descriptions (e.g., ‘Excessive focus can block ideation’) gradually maturing into more evocative wording, often flavoured with children’s descriptions (e.g., ‘Don’t think…act’). Some descriptions would be left, even late on in the process, without thematic homes. This meant three possible outcomes: the orphan description leading to a regrouping and renaming of themes to allow it to fit; the orphan description, in capturing something vital not yet encapsulated in another theme, being elevated to theme status itself (an example of this was for Snowy and the theme ‘Go in with eyes open, only later switch on judgement’); or the orphan description being deemed an idiosyncratic or uninformative one-off, in which case it being dropped from further analysis (an example was ‘Remembering and applying a creative rule from a teacher’).

This process normally resulted in the production of between 9 and 15 themes per child. The next stage of the analysis again involved a recursive process to group themes into fewer, meaningful over-arching themes – the primary themes. The process is a more contained version of the preceding one, in the sense that the numbers are much smaller. The final number of these primary, over-arching themes was between 3 and 5 per child.

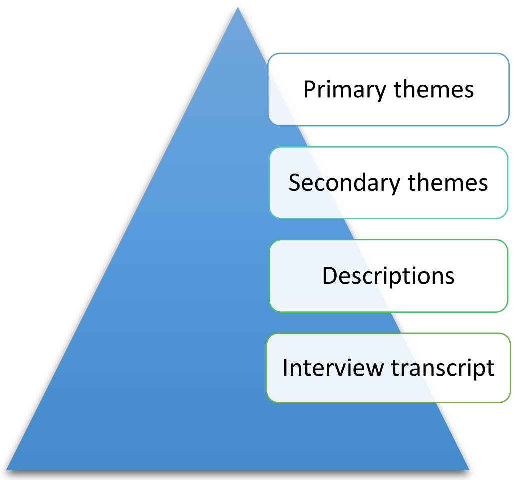


Fig. 3. 1 Levels of analysis from raw interview data to final themes

Once the analysis for a child was complete, a summary document was produced which included a tree diagram showing their primary themes, the secondary themes which comprised them and a quote to illustrate the essence of that theme. In addition, an idiographic narrative was created for each child, with illustrative quotes focused on the research question: *How do control process contribute, positively or negatively, to this child's creativity?* Four illustrative idiographic narratives follow in the Findings section and the remaining 10 are in the Appendix.

As the analysis proceeded through multiple children, there evolved a more reciprocal relationship between induction and deduction and between themes and descriptions. In other words, as there was more familiarity with the material and an observation of recurring themes, it became possible to 'see' a theme quite early on in analysis and to spot descriptions which would fit within it. Obviously, one must be slightly cautious of this approach and continue to be rigorous about checking for best fit in both the overall selection of themes and in the assignment of descriptions to them. The final stage of the analysis involved pooling the data from all the children to see similarities and differences across their accounts and to draw out the group level primary and secondary themes.

Methodological integrity

Given there remains scepticism regarding the validity of introspective techniques applied to cognitive thought and that this type of approach with children is novel, I wanted some way of ‘stress testing’ my data. I developed a checklist, ‘The 7 Cs’, to aid a critical approach to assessing the validity of the data. I would ask whether each child’s data was sound in terms of:

- Cooperation. Was the child willingly and happily involved?
- Consistency. Did the child’s account at different times match up?
- Confirmation. Did their accounts concur with secondary evidence (e.g., the video evidence demonstrating the order in which events occurred)?
- Corroboration. Did the child’s account corroborate well-evidenced descriptions in the creativity literature (e.g., functional fixity)?
- Contradiction. Did the child correct my version of their account, thereby showing a greater degree of certainty of their own?
- Coherence. Did the child’s responses make sense?
- Confidence. Did the child articulate their thoughts with certainty?

The *7Cs* were used as a general guide in checking each child’s account. All seven were not necessarily present in every account (sometimes there were not examples to test, for example, ‘contradiction’) but there were always at least five. Perhaps more importantly, the process of checking meant that validity was under regular critical review.

Findings and analysis

The analysis distinguished three primary themes into which children’s thought processes fell. I will use these to frame the presentation of the results, the analysis and discussion which follows.

- First are those descriptions of thought which appear to be spontaneous, free-wheeling, and uncontrolled. Ideas, refinements, or adaptations arise without deliberate effort, from the senses, from memory or from new associations being spontaneously made.
- Second, there are those descriptions of thought which appear controlled or focused; these are ideas being deliberately elaborated, planned out, evaluated, adapted, or even formed anew in a deliberate, strategic way.
- Third is the category that describes processes concerned in various ways with adjusting the balance between spontaneous and controlled processes; these include managing and adapting constraints, switching between spontaneous and controlled processes either spontaneously or deliberately and also include those dimensions which describe failure at the extremes, specifically, an excess of control leading to a lack of free flowing ideas or overly strict censorship, or an excess of spontaneity leading to an overload of ideas and difficulty selecting from amongst them.

These themes are illustrated in Fig. 3.2 below, to show the relationship between them. The relationship is conceived as a balance beam, with spontaneous processes at one end, control at the other and balance processes as the means by which the beam is moved.

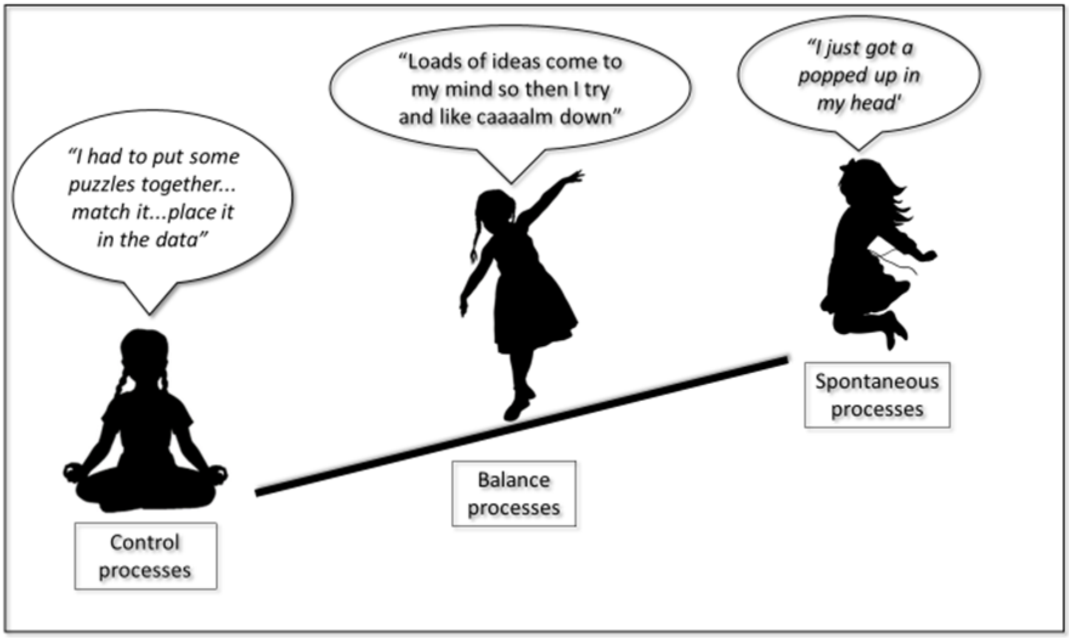


Fig. 3. 2 The three primary themes of creative thought, with illustrative quotes.

Figure 3.3 shows the three primary themes and the secondary themes which comprise each of them. Each theme will be outlined in the analysis that follows, with illustrative quotes from the children, written verbatim. The overview serves to situate each theme within the overall analysis framework.

Theme 1: Spontaneous processes
1.1 Spontaneous ideation: ideas from the senses
1.2 Tales of the expected: ideas from memory
1.3 Ideas without effort: free association
1.4 Open to the new

Theme 2: Control processes
2.1 Ideas through effort: you can force it
2.2 Planning and focus
2.3 Puzzling it out: evaluation and analysis
2.4 One small step for creativity: elaboration and adaptation
2.5 Lack of openness

Theme 3: Processes which speak to the balance between control and spontaneity
3.1 Spontaneous AND controlled: balancing act
3.2 Controlling the controller: managing constraints
3.3 Creativity fails at the edges (excess control or freedom leads to failure)
3.4 Jack of all trades (contributions from spontaneous association, effort, senses and memory)

Fig. 3. 3 Overview of primary and secondary themes

Theme 1. Spontaneous processes

The description of ideas as ‘popping’ into children’s heads was almost ubiquitous:

Snowy, ‘I just got a popped up in my head’

Dooda, ‘They just pop up’

Maria, ‘Oh yeah that idea popped into my head’

Betty, ‘This one popped into my head really quick’

Alex, ‘The antler popped into my head’

Kitty, ‘I think it just pops up when you look at stuff’

Children used this term to describe the experience of an idea, an association or a new thought just arriving unbidden into their heads, apparently exempt from planning or effort. For some children, this seemed to be their predominant type of creative thinking, often coupled with sensory acuity and ideas flocking in from the senses, particularly the eyes:

[Is there anything that makes it hard to have ideas?]

Snowy, ‘Yes. Closing your eyes. Or looking at a blank screen’

Lexy, ‘When I’m in my bedroom and it’s dark and I’m nowhere and I can’t find anything to give me inspiration’

1.1 Spontaneous ideation: ideas from the senses

For some children, this spontaneous ideation was primarily driven by the immediate environment, by perceptual experience in the here and now.

Dave, ‘[When I] look outside there are there’s birds in the sky, so I think I’ll draw a few birds’

Snowy, ‘If I’m seeing it gives me an inspiration what’s around me’

Kitty, ‘When you look you see stuff and you just like combine it together’

Some children were clearly aware that their senses were the main source of idea input. When asked where ideas come from:

Dave, ‘…you might like see or hear or any other of your senses, like see or hear are the easiest ones, and you see something and then you say “Aha” I wanna do that’

The contribution of the immediate sensory environment extended to ideas coming from the body, with several descriptions of the body leading the mind, without apparent inhibition from the brain. In some cases, this embodiment appeared to kick start the creative process:

Alex, ‘When I started to like actually draw I actually got the idea what I was gonna do’.

Other children described how the physical movements involved in drawing led to other ideas:

Kitty, drawing waves in an ocean which ebbed and curled said, ‘I think that’s when it came…I think my hand was going first…my hand just went up and down….’

Harriet, talking about how she had drawn a chimney on a tree instead of the roof of a house explained, ‘My hand did it because my brain kinda hadn’t caught up with me’.

The notion of the body kickstarting the brain was also referenced in the context of how children would remedy a feeling of being stuck. The way, it seems, to get out of a rut is not to think, but to *act:*

Snowy, ‘I just said some random words…it just helped me with what I was going to say’

Dooda, ‘When I start drawing it gives me ideas’

1.2 Tales of the expected: ideas from memory

Children also described their ideas coming from a range of memory sources, including life experiences and memories from stories. When asked where their ideas came from:

Harriet, ‘from thinking of all the ideas I’ve had…all the books I’ve read which are a billion’

Imagination Creation, ‘from things you do, read, watch, anything like that’

Betty, ‘I might use the same ideas from the movie…I just change a few things’

Silky, ‘We’ve been reading this book called erm ‘The magic faraway tree’ by Enid Blyton and I decided to draw it here’

Maria, ‘My cat sleeps on the bed upstairs so that’s how I got that idea’

1.3 Ideas without effort: free association

The final type of spontaneous process consistently described concerned the forging of new associations, connecting elements from memory, or from the senses, or a combination of both.

Snowy, ‘The blackberry popped in from the TV and this abacus here - because the TV is how black the blackberry was and one of these balls is how small the blackberry was’

Imagination Creation, ‘I was actually like thinking I like superheroes and I like powers duplicating things and also the one that could shape shift that also came, I was also going to do broccoli but if I did corn that could turn into popcorn so that was enough so yeah ….if its corn then its popcorn so it’s kind of like a real shape shift.’

Ben Ten, ‘Then it made me thought of Heat Blast because the sun’s fire and Heat Blast is made out of fire’

Betty, ‘The idea popped into my head to do the hawk I realised that because the chicken is a type of bird’

Dave, ‘Well I did have the idea of a robin that’s why I did red’

Not all ideas which arose by this spontaneous associative process were ultimately selected, suggesting that more deliberate evaluative processes came into play immediately following the spontaneous ones.

Silky, ‘I thought of a monkey but I didn’t really want to do a jungle so I chose a frog’

Lexy, ‘I thought if I draw a fish I need to draw water and if I draw water I need to draw more things and that would take for ages’

1.4 Open to the new

The final catalyst for spontaneous creative expression was more a trait-like theme of broad openness and receptiveness. Several children alluded to their liking for things which were new, unusual, even strange - and which might arise from the senses, from memory or from freshly made chance associations.

Dooda, ‘I’ve drawn a lot of rabbits and I know I like rabbits and I want one as a pet and I like them but I want something new and different’

Harriet, ‘I just like strange things… cos they’re interesting’

Imagination Creation, ‘That’s kind of my thing I just love unusual stuff… like when it’s usual it’s boring’

New things have the potential, quite simply, to bring about new thoughts and ideas.

Snowy, [Why do you like new things?] ‘Because they get your brain working’

Theme 2. Control processes: fitting in

On the flip side of these spontaneous, open, freer processes are those which fall under the broad category of control: those aspects of the creative process which are deliberate, effortful, or tightly focused.

2.1 Ideas through effort: you can force it

There were several accounts which suggest that, albeit relatively rarely, ideas can emerge not through spontaneous 'popping up' but through deliberate effort. This might be through such strategies as exploring broad categories or by dismantling or rearranging parts of a fledgling idea.

Dooda, 'I'm trying to think of a shape that it's in, and what it's got on to like for ears…I'm thinking of all the animals that have small ears'

Roxy, 'I just try and like…maybe swap parts of it or look at it from a different angle or step back and see if I can see something else'

Many children recognised that creativity was judged in part by its unusualness or even wackiness and strove to achieve this goal through strategies, such as deliberately selecting for weirdness.

Harriet, 'I wanted it to be strange colours so I made sure I didn't do the leaves green… I was just like taking…a random pen to make it look like an unusual colour'

Imagination Creation, 'At the back [of my brain] are the crazy bits but like here [forehead] yeah like here is sensible and… I have to push a way through to the back'

2.2 Planning and focus

Nearly all the children were very focused on producing their creative work, concentrating for 30-55 minutes without a break. Several talked about the need to plan out their work.

Maria, 'If you pick up the colour…it looks one way and then when you try it out if looks a different colour and it might be that you didn't want that colour so you have to test it out to see if you like it first'

Dooda, 'I want to take my time I don't want to rush it'

Silky, 'I was focused on my picture most of the time…When I was drawing my dock erm and I hadn't drawn fishes I decided to add fishes but finish what I was doing first'

Betty, 'I knew I had to go back over things so I thought to just do it at the end'

Some children had clear awareness of the way in which they needed to work in order to accomplish the task most effectively.

Dooda, 'It would be harder if I went like castle then table then castle table castle table I might as well on by accident do something wrong if I forget my plan but I don't want to forget my plan so I do it in order'

2.3 Puzzling it out: evaluation and analysis

There were notable differences in how children described the process of evaluating candidate ideas for selection. For some, idea generation - predominantly a spontaneous process - and idea evaluation - predominantly a control process - appeared to be quite distinct, while for others they were almost coincident, with a 'kind of overlapping in my mind' (Imagination Creation).

Dooda, exemplified the first type, describing how ideas first piled up and then:

Dooda, ‘I feel very confused because I I’m not sure which one to take’

By contrast, for Imagination Creation, idea generation and evaluation were sometimes barely distinguishable, with ideas emerging, being judged and the next idea appearing without pause:

Imagination Creation, ‘Camel I was thinking about sand but no but monkeys with bananas yeah I like that’.

Children sometimes invented elaborate devices for evaluating ideas, sometimes bringing reality back into imaginary scenarios to judge ideas

Lexy, ‘A house could be in the background but who would want to live behind a Viking ship with Vikings shooting cannons? No one’

Sometimes several evaluative tools were used simultaneously. Dooda, explains her complex algorithm for evaluation:

Dooda, ‘So for an example, if I had a castle and London Bridge, London Bridge is a landmark… and the reason I would want to take it is it is a landmark and landmarks are interesting. But I would also want to take a castle it’s because houses are my favourite so I thought which reason was the best and I thought I think the house one was the best and so I chose the castle.’

Just as the word ‘popping’ was the trademark of the spontaneous generation of ideas, ‘fitting’ was the word nearly all children used to describe controlled evaluation. For Imagination Creation, 9, creativity came in the form of a jigsaw puzzle, requiring methodical thought for the best fit.

Imagination Creation, ‘Yeah like in my mind I had to match it, like it doesn’t fit there and like yeah how about here then I thought what I can do there and place it in the data’

Betty, expressed a simpler, more serene variant of a similar approach:

Betty, ‘I chose it because um mermaids are normally in the sea and that would fit with my lake’

Logic played a big part in many children’s descriptions, with many expressing active dislike for things which did not make sense according to their experience of normality.

Dave, ‘Do pigs live in sandy places? No. Would a witch want to be in a desert to do a spell? I don’t think so’

Maria, ‘You also should need a window in your house…because otherwise it would be really dark’

Lexy, ‘I knew I wanted to pick the sun because what’s a picture with no moon no sun cos if I’m doing something outside I need to add something for the sky’

It was also in the evaluation of ideas that descriptions of working memory were often evident, as multiple ideas were worked with simultaneously.

Snowy, ‘My brain fits loads of things at once for example I could think of a kangaroo and a million elephants’

Roxy, ‘My mind… was a frenzy…when your brain’s so full of it you find it hard to like to like get down to earth again’

Some children had the know-how to offload some of this cognitive burden onto the environment:

Maria, ‘Sometimes you forget your ideas so I’m going to jot it down as soon as possible.’

2.4 One small step for creativity: elaboration and adaptation

Control processes were widely in evidence in the small elaborations, adaptations and refinements that are customarily part of the creative process. The elaboration phase is often a time for 'taking a step back' and trying to look at your work with new eyes, scrutinising it for imperfections or places with scope for greater precision, detail, or flourish. As illustrated by Harriet's quote below, it can also sometimes mean simplifying, stripping back rather than adding layers.

Silky, 'I tried the white one but it didn't work… I tried it on top of another one and it worked'

Ben Ten, 'I made this bit a bit shorter because last time it went too long and I curved more because last time I went straighter'

Harriet, 'Well first I thought of the steps and then I thought I'd do it like the tree trunk is cut in half so you could see the steps but then I decided that was too difficult so I just did a normal tree trunk'

2.5 Lack of openness

There were many levels at which a lack of openness was made manifest – from the sort of cognitive fixity widely recognised in design research all the way up to the broader sort of social inhibition which prevents deployment of an idea which might appear silly, wrong, or just plain weird.

Alex, 'No I I like no I don't like things that are too odd'

Dooda, 'I was going to pick it but I said no to myself…I thought how about we put more of those but I said no'

Lexy, 'I don't want to draw a chicken bone cos that's weird'

Dave, ‘I knew that I wasn’t going to use that one because that doesn’t make any sense at all’

Kitty, ‘I didn’t want to do it like that because that would just be weird’

Functional fixity – the well-established finding that it is hard to see an object in a different way having first experienced its primary function, was very well expressed by one child.

Roxy, ‘Once I’ve got one image in my mind…I kind of find it like a bit harder to like find a different one you know what I mean? When I see it again I think ‘That’s a hand what else can it be hmmm… I know… a hand!’

Theme 3. Balancing control and spontaneity

The final component in the triad of thought processes is that concerned with modulating the balance between spontaneity and control. The modulation exhibited and described by the children was sometimes deliberate, sometimes (for example in response to distraction or accident) spontaneous. For some it was determined by a change of domain (for example, a different control/spontaneity balance in drawing vs. planning), for others by a change in the degree of freedom or constraint (for example, application of a rule shifting the balance to higher control). For still others it was determined by the stage of the creative process, with earlier more generative stages being freer and more open, and later stages more rigorously controlled.

3.1 Spontaneous AND controlled: balancing act

Several children described a quite deliberate shift between a primarily controlled and a more spontaneous thought process, pointing to sophisticated metacognitive awareness:

Betty, ‘I normally just concentrate… then I realise I’m concentrating too hard and then that’s when normally when my mind goes blank and then I sit back and then I relax and then after it comes back to me… so it’s like my mind is telling me to stop working and then when I relax it comes, the idea comes back to me…I think maybe my mind just does it cos it's cos it's telling me to just relax'

For Roxy, the balance shift was clearly in response to the stage of the creative process she was engaged in. She describes how her freewheeling approach in the idea generation phase was followed by a cooler controlled approach once it was time to evaluate those ideas:

Roxy, 'If I was thinking of a subject immediately like loads of ideas come to my mind so then I try and like 'Caaaaalm down' and just find one that really captures me'

For Imagination Creation, as was characteristic of his multitasking approach, there was less a specific shift between control and spontaneity and rather the ability to use both simultaneously:

Imagination Creation, 'I've got like this core thing where…when I'm *saying* I can also think about things… so I can kind of do it while I'm doing other things… while I'm saying lalala I can also think about what's going to happen next'

He further described this pot pourri of thought processes with the analogy of a video projector in his head which brought ideas from the far reaches of his brain 'it just came from deep inside let's say' to the front for a systematic review:

'I have more like this… screen here [holding up imaginary screen on forehead] and then pictures – whoop! No oh maybe yes no do the next one next next next maybe yes maybe no then another one here another one here then swap it… [Int: and you're pointing to your forehead…] IC, 'Yeah!'

For Lexy, it was often her distractibility which precipitated a new, unplanned idea – but quickly after it would be evaluated, adapted, and selected or rejected:

Lexy, ‘That’s just a mummy cheetah and a baby cheetah what’s going to get a bed to sleep on [Int: Where did that idea come from?] I I because when my cat walked past I remembered and then I thought cheetah’s in the cat family so I wanted to draw that’

Even one of the youngest children, Dooda, (7) gave descriptions which showed a high awareness of the need to sometimes augment the control side:

Dooda, ‘I wanted to rush but I said no I don’t mind Cathy said “Take your time” and it’s good to take your time just like an artist would do’

3.2 Controlling the controller: managing constraints

Many sources, both internal and external, led to a temporary or permanent change of constraint. In managing these changes, children demonstrated their ability to tip the balance beam towards more controlled and more spontaneous processes. The role of the imagination came into play here for several children. Evocatively described as ‘Idealand’ by Dooda, the imagination is seen as a place of increased freedom from constraints. Others agreed:

Dave, ‘There’s no such thing as a giant bird…unless you’ve drawn one’

Alex, ‘If… like a bird pops into my head but that doesn’t really look like a wing I could say erm it was like going to be a mythical bird or something’

Dooda, ‘When I thought of Dover castle it didn’t really have bricks but I thought that it doesn’t matter I’m not drawing Dover castle’

A small change in perceived rules, even something as simple as which way up a stimulus shape was held, could be enough to prompt a loosening of control:

Dave, ‘That’s only pretend things I can make out of that one… I can only… but if I moved that piece around [turning it upside down] and I put it there that could be a leg and if I put four more it would be like the legs of an animal and that would make sense’

Alexandra, [When did you decide to have the paper that way up?] ‘When erm when you said we don’t have rules’

Roxy elaborated further on this theme, talking explicitly about how the introduction of a constraint (e.g., having to draw a picture about something specific rather than anything at all) has differential effects on different aspects of the creative process. In particular, it illustrates how, from her point of view, there is no control over ideas coming in, but control plays a role in the subsequent selection from those ideas.

Roxy, [When there’s something that you have to include, does it make it harder to come up with ideas?] ‘Well… it doesn’t make it harder to come up with them, it makes it harder to find the one that will work’ [And what about if you’re given nothing, no rules, how would that have felt?] ‘Then my mind would have been a frenzy!’

Accidents and mistakes played their part in offering up new opportunities which were often met with a freer, more open, more spontaneous response, even from children previously more tended towards control:

Alex, ‘Like if you get something wrong you can always like er it doesn’t really matter because you can just turn it into something else…like in this picture I was about to rub out the roof but then… I thought that it would be cool if it was like this side was haunted and this side was like really cool like good…and like the worms are escaping from the unhappy side and then going to the good one’

Harriet, ‘Well the chimney was a bit weird because it’s sticking out of the tree rather than the house…my brain kinda hadn’t caught up with me so I just drew it on the tree and then I realised that I just wanted to keep it like that’

Maria, ‘I didn’t plan that to happen!’

For Lexy, who had previously described a positive creative outcome from distraction by her cat, was also aware that succumbing blindly to every distraction was probably not a winning strategy. She describes how, at another point of distraction in her drawing, when a car’s horn started beeping loudly in the street below, she had to tip the balance back towards greater control:

Lexy, ‘So I was trying not to do that [get distracted] so I was drawing but if I heard the beeping noise it would remind me of a car and I might start drawing a car on water…I didn’t do it because I reminded myself I was doing that.’

3.3 Creativity fails at the edges (excess control or excess freedom lead to failure)

There is the risk of failure at both extremes of control and spontaneity, each with distinct implications for creativity. Excess control limits the free flow of ideas, reducing quantity and thereby reducing the chances of surprising, novel associations and ideas. It therefore means risking failure primarily on the *originality* dimension of creativity. Excess freedom, on the other hand, produces sufficient quantity and diversity of ideas but without sufficient control could lack the ability to select meaningfully and effectively from them. It therefore carries the risk of failure on creativity’s *value* dimension. Children showed examples of both.

Excess control often meant a head empty of ideas, either through prematurely shutting down avenues to early-stage ideas or, maybe due to a feeling of pressure, neglecting to produce ideas at all.

Alex, ‘I just couldn’t think of anything…I thought like the sun but that’s a bit boring’

Betty, ‘My mind went blank a few times’

Kitty, ‘I was feeling nervous because… I didn’t know what to do’

By contrast, too little control (excess freedom) was suggested by descriptions evoking a head full of ideas flying around with no way for ground control to call them in:

Roxy, ‘They were all zooming around and I was just yeah maybe I was a bit indecisive’

Dooda, ‘When you think of lots of things well my head just start hurting and I just had a headache’

Imagination Creation, ‘A bit cloudy because things were overlapping with stories and stories I’ve read…kind of overlapping my mind’

There were a few examples where children could see, after the event, that they had been either excessively controlled or excessively free. Kitty, talked rather ruefully after finishing her picture about some of the missed opportunities she could now see:

Kitty, ‘I could have used different colours…I could have changed the colour of the sea and the mountains the sun and the moon I could have changed the gas in the clouds… but I didn’t… I just wanted to draw a creative picture but I don’t think I did one so I think I’ve just done a normal picture’

By contrast, Snowy, who overflowed with ideas said, before watching the video playback, ‘I’m so scared to see my story’ as if what she had produced moments before could be a surprise. This suggests she had been deploying thought processes immune from control – or acting without thinking. After we had finished watching the video, when I asked if she would change anything about her story, she said ‘Lots’. Like what?

Snowy, ‘Like the raspberries the basket the lion the present the mountains raspberries strawberries parrot’

In short, almost every component of her story. Only after the fact could controlled evaluation take place.

3.4 Jack of all trades (spontaneous association, effort, senses, memory)

The shuttling between freedom and control described by the ‘Jack of all trades’ theme is harder to illustrate with single quotes, since it arises more as a feature of certain children across their whole transcript. In other words, it describes children who, over the course of producing their creative work deployed several diverse approaches to creative thinking, some controlled, some spontaneous, sometimes exploiting the immediate sensory environment, sometimes exploiting memory.

Lexy provides an illustration of this. While she was drawing, she accidentally knocked a star-shaped paperweight off the table and it fell with a thud onto the floor. She immediately picked it up, placed it in the sea of her picture and drew around it. When asked about incorporating the star, she said:

Lexy, ‘I didn’t have the star in my mind I only had the star when I dropped the star’, showing how she moved from concentrating on her picture, to an accident bringing about a spontaneous idea to a controlled inclusion of that idea in her evolving picture.

Similarly, Dave, described a subtle shift between freer, associative, and controlled, logical thought processes:

Dave, ‘I chose the sun because it looks exactly like a sun… I started to have an idea that it would be really hot… that’s why I was drawing the sweat on the camel.’

[What happened here when you drew a smiley face on the camel and then rubbed it out?]

Dave, ‘I changed it to a huffh [making panting face] and that was because I thought it would be really hot and would you have a smiley face if you were really hot? I don’t think so’

These sections have illustrated the primary and secondary themes of the analysis as they pertain to the group as a whole. There were many aspects which were common to the group – for example, a greater evocation of spontaneous processes in the generation of ideas and of control processes in their evaluation. But there were also differences. The following section adds to this analysis by looking in more detail at four individual children.

Idiographic thematic narratives

Short summaries were produced for each child, using a combination of my analysis and observations and the children’s own words, to illustrate their individual creative approach. The purpose of these is to provide an alternative lens through which to view the same analysis; it focuses less on the commonalities of the creative process within the group and more on the differences between individuals. Four narratives are included below; the rest are included in the Appendix.

Lexy

Single line summary: Distractions can beget ideas, but they can also be…distractions

Lexy is very open to ideas (‘I just find ideas everywhere’) and has no difficulty, when presented with a new stimulus, in fluent divergent thinking (‘I thought this one this looks like a flag actually it looks like a record player and then it looks like candy floss’) without apparent effort.

Her description of what would make it hard to have ideas was striking and poetic ('…in my bedroom and it's dark and I'm nowhere and I can't find anything to give me inspiration and there's no one to give me some clues… only myself and a blank head… so I can't think of anything') and captures both the sensory and the social dimensions of creative thinking.

She appears open to possibilities which arise by accident ('I didn't have the star in my mind I only had the star when I when I dropped the star') and from events happening in the world around her, even if they shift her planned creative path ('Because when my cat walked past I remembered and then I thought cheetah's in the cat family so I wanted to do that') whilst also recognising the danger that blindly incorporating distractions could lead to undesired results ('If I heard the beeping noise it would remind me of a car and I might start drawing a car on water'). During the interview, she was frequently distracted by things going on around her ('I don't know I just wanted to…. So can it project anywhere?') and restlessly played with different toys.

The downside to this ability to see endless possibilities in the world around her is the effort it takes to decide whether or not to process that information ('[My mind] wandered to my water bottle… then I thought em… I don't need water'). She was sufficiently familiar with this need to monitor and contain distractions ('I do this all the time'), that she recognised it and acted on it ('I didn't do it because I reminded myself that I was doing that') in a way that suggests a metacognitive awareness of the need to activate her control processes.

In evaluating ideas, a slightly different picture emerged. She was a harsh critic of her own ideas, having no truck with ideas which were too fanciful ('who would want to live behind a Viking ship with Vikings shooting cannons and mountains?'), too boring ('I thought why should I draw a feather duster because that's not very interesting') or too odd ('I don't want to draw a chicken bone cos that's weird') or on the basis of rules she had set for herself ('I went to Italy there was a castle with a mountain and then I thought I shouldn't copy'). There was a lot of creative thinking in her evaluation of ideas ('who would leave a Viking boat out at sea floating with no Vikings?'), suggesting that her imagination played a part in both divergent and convergent aspects of the creative process.

In short, she is in some ways the ideal creative: open to all possibilities when it comes to input of ideas, then highly critical of which to feed into output. Freedom and control in harmony.

Alex

Single line summary: Default is handbrake on, but accidents, mistakes and action can ease it off

Alex presents a complicated story. For him, creativity is an effort, something that must be concentrated on and worked at, rather than something spontaneous and effortless. There seem to be a number of self-imposed constraints – things cannot be too 'crazy', too 'weird', too 'wonky'. In other settings, notably at school, he would rein things still further ('I wouldn't do it as crazy as this'). He shows patience and controlled planning ('Mostly yeah I knew what I was going to draw'). Ideas are not in abundance ('I just couldn't think of anything') and there is little evidence of spontaneous generation or combining of idea fragments.

When he starts drawing, the rules seem to change. He is distracted ('I forgot about it when I was actually doing the picture'), prone to error ('I drawed the house big by accident') and open to the possibility of changing direction ('I always like change what my initial plan is when I actually draw'). In short, the relationship between creativity and control seem entirely to change.

His default position seems to be having his control handbrake fully engaged. He prefers creative activities with rules ('I just er go on the internet and have a step by step guide like how to draw it') and to keep within limits ('No I I like no I don't like things that are too odd'), resulting in a head quite often empty of ideas ('I didn't really actually have any ideas to draw'). But when there is the possibility of releasing constraints, for example by moving from the real to the imaginary world ('That doesn't really look like a wing I could say erm it was like going to be a mythical bird or something') his creativity seems to flow more freely. It is still not necessarily spontaneous; rather, he gets into situations where he is forced to get out through creative problem solving. It is almost as if he needs this pressure in order to think creatively. To put it another way, he will accidentally get into creative trouble, then effortfully, logically and analytically get out of it. ('If you think about it like you concentrate and you think about it you're probably going to get an idea'). His creative strength is more convergent than divergent.

A good example was his submarine. He was in a quiet meditative moment, colouring the waves in blue. Because he was somewhat distracted, he didn't realise he had drawn the waves *under* the submarine (i.e., as with a boat) instead of above it. ('I was gonna make the submarine be like underwater but then I accidentally drawed it like that so I had to just erm draw this that it's like coming back in to the village'). He came up with a story for why the submarine was above the water –it was returning to shore, a novel aspect not in the blueprint. Another example was in the mistake of the asymmetric roof, again part of a doodling, slightly absent process which meant that the two halves of the roof were uneven. Rather than reject this, he took it as an opportunity to create a story, here making a parallel between physical and moral asymmetry and turning one half of the house 'good' and the other 'bad' ('I was about to rub out the roof but then… I thought that it would be cool if it was like this side was haunted and this side was like really cool like good…and like the worms are escaping from the unhappy side and then going to the good one').

This was arguably the most creative aspect of his picture, and one that was brought about by a cocktail of error, openness to change and a pleasing example of creative thinking in metaphor.

Imagination Creation

Single line summary: Crazy ideas at the back corralled by control at the front

Imagination Creation seems caught in a moment to moment battle between spontaneity and control. This makes it hard to characterise different control processes operating on each stage, since the overall picture is a multi-tasking, open-minded strategic thinker who is switching continually between contrasting thought processes (‘While I am saying lalala I can also think about what’s going to happen next’). Idea generation and idea evaluation are often almost coincident.

Very open to ideas, (‘That’s kind of my thing, I love unusual stuff’) Imagination Creation has an appreciation of and an appetite for the fact that ideas can come from everywhere, particularly for children (who still know how to ‘play around’ with ‘ideas sucking into their brains’). These stimuli are picked up and played with both unconsciously (‘well that actually tumbled out of my mouth’) and deliberately (‘I had to match it, like it doesn’t fit there and like yeah how about here then I thought what I can do there and place it in the data’). For him, creativity is a puzzle solving exercise, where pieces, absorbed from the environment, are then slotted together using learned tools and techniques in a strategic and controlled manner (‘yeah so start middle twist, I actually got that from a movie’). The considerable effort required for this juggle is clearly felt, as illustrated by the ‘cloudy head’ which comes when ‘too many ideas are overlapping’, or in the fight to get past the ideas ‘at the front’ to the ‘crazy ones at the back’ which seems like a description of suppressing control in order to travel further afield, to exciting unexplored nodes in associative networks (‘It just came from deep inside let’s say’).

The overcrowding suggests a working memory sometimes stretched to full capacity and then strategically offloaded to the environment. The consequence of the overcrowding means that sometimes well planned moves are imperfectly executed in practice (‘I erm I forgot to say they pressed another button…’) Inhibitory control is harder to characterise; some evidence of it in action, for example in rejecting ideas for being ‘too weird’ but in other ways it seems to be deliberately suppressed in order to maximise ideational input and the ‘good stuff’ at the back (‘Well bad ideas are still goo…are still ideas, they might be useful for something else’).

Similarly, he seems in some ways flexible, shifting rapidly from generation to evaluation, deliberate and spontaneous thinking – but in others, not; for example, in ‘not being ready’ for a change of direction when I invited him to add to his story. Simultaneously nervous, primed for action (‘kind of butterflies in my stomach… actually in my head… everywhere’) and calm, even cool, and relaxed (‘oh it just goes through lots of ideas yeah selecting things out’).

There is a good deal of talking in imagery and metaphor on many levels. His description of ideas as images hurtling from the back of his brain to the film projector at the front which flashes them up on his forehead for selection or rejection, is wonderfully vivid. And evokes a sense of idea generation being based on finding distant associative connections from all over the brain (‘it wandered everywhere really looking for parts’) which are then formally evaluated and assessed at the front of the brain (‘to see that it fits into my story’). The story he created, with its examples of spontaneous combining, shape shifting, running out of control then taking control back again (plus a bit of magic and a rogue monkey) is a wonderful metaphor for his own creative process. [The story is included in the Appendix.]

Snowy

Single line summary. Go in with your eyes wide open

Snowy was uninhibited in terms of the spontaneous generation of ideas (‘a hat can be a lady’). She enjoyed seeing the world from different angles (often literally, doing gymnastics, somersaults off the sofa) and having ideas butt in and interrupt her whilst she was in the middle of talking (‘kind of also like a roly-poly… or a leaf it goes up into the air and flies somewhere’). She often spoke of things ‘popping up’ to describe how ideas arose (‘I just got a popped up in my head’, ‘the flower popped up from his eye bulb’) apparently without effort or concentration. She was highly sensorially alert – wide open eyes hoovering up stimulation from the environment (‘if I’m seeing it gives me an inspiration’). She understood this reliance on visual input; what would make ideation hard would be ‘closing your eyes. Or looking at a black screen’.

She gave several examples of spontaneous associations, for instance in the substrates for the poisonous blackberry in her story (‘the blackberry popped in from the TV and this abacus here because the TV is how black the blackberry was and one of these balls is how small the blackberry was’). She would sometimes deliberately act without planning or forethought, saying that doing rather than thinking would help progress (‘If I just started it would make more ideas come’) and spoke of the utility of her physicality (‘it goes zzzz it goes all excited and it just brings fresh ideas into my head’). The state she described when fully involved in her creativity suggested a kind of flow (Were you concentrating hard? ‘Not really’), a focus without deliberate effort.

There was evidence of large working memory – both from her own account (‘My brain fits loads of things at once, a kangaroo a million elephants’) and from her impressive extemporising using many characters and elements from her story, sometimes in long repeated lists. There was not much evidence of advanced planning, with events seeming to tumble on from one another quite haphazardly ('I might use the lion because it popped up in my head and I think I will make a really good story with the lion').

Control processes played a significant role in the evaluation of the story, but only after the event ('I'm so scared to see my story'). Only too late, after watching it back, did stricter judgement come in as she insisted she would change 'everything…the raspberries the basket the lion the present the mountains raspberries strawberries parrot'.

Discussion

Determining the brain basis of creativity hinges on understanding creative behaviour and the cognitive components which underpin it. Qualitative research, with its focus on process rather than product, has potential value in informing cognitive theories of creativity, using children's accounts of creative process to generate hypotheses. This study set out to examine the contribution that executive control processes made to children's creativity, using video stimulated recall of their thought processes while they were involved in the production of a novel creative work. The subsequent theoretically driven thematic analysis found that children's descriptions fell into three broad themes: spontaneous processes (ideas arising unbidden, unprompted associations), control processes (planning, evaluating, strategic approaches) and processes which described the balance between these two extremes. Put most simply, these processes can be characterised as those that occurred outside of executive control, those that were tied to executive control and those that determined the extent of executive involvement.

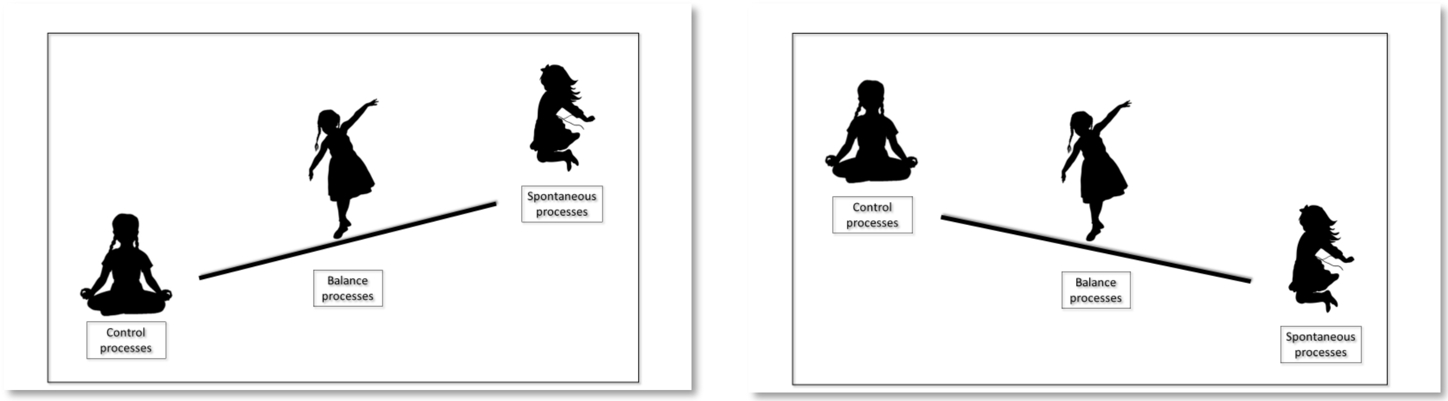


Fig. 3. 4 Illustration of the three main themes derived from the analysis and how balance processes can shift the emphasis from more spontaneous (left) to more controlled (right) processes

The notion that non-executive (associative) and executive (analytic) processes are involved in creativity has been widely recognised by creativity researchers over several decades (Beaty & Silvia, 2012; Bowden et al., 2005; Mednick, 1962; Nusbaum & Silvia, 2011). More recently, neuroimaging studies have provided evidence of these disparate processes at play during the creative process (Beaty et al., 2018; Limb & Braun, 2008; Liu et al., 2012). Some researchers have even sought to enumerate the contribution of these different processes to creative cognition for example by using analysis of semantic distance of responses to represent associative processes and fluid intelligence measures to represent analytic processes (Beaty et al., 2014). The combination of these two ingredients also lies at the heart of several influential cognitive models of creativity, including the ‘Geneplore’ model (Finke et al., 1992) introduced earlier, which primarily describes a recursive shuttling between association (generation) and analysis (exploration).

The finding in this study that these processes also appear to be core components of the creative process in children suggests that similar processes are at play as in adults. This is perhaps not hugely surprising. What is more interesting is the idea that the balance between these processes – and the flexibility to modulate that balance – might also be a key part of the process. As others have suggested (Zabelina & Robinson, 2010a) creative success might depend less on executive control ability per se and more about an individual's flexibility to modulate it according to task demands. The children in this study exhibited and described many manifestations of such a modulation. It was sometimes deliberate - precipitated by the metacognitive realisation that a change in approach was needed, and sometimes spontaneous – happening, for example, in response to distraction or by accident. For some children, it was governed by a change of domain (for example, a different balance between control and spontaneity was seen when planning what to draw than when actually drawing); for others, a change in the degree of freedom or constraint tipped the balance (for example, having to apply an explicit rule shifted the balance away from spontaneity and towards higher control); for still others, it was determined by the stage of the creative process, with earlier more generative stages being freer, more open and spontaneous, and later stages more rigorously controlled.

This characterisation has some striking parallels with recent models derived from the adult literature (Chrysikou et al., 2014; Mekern et al., 2019; Nijstad et al., 2010; Pringle & Sowden, 2017b; Zhang et al., 2020). To my knowledge, there are no equivalent models for children. Consideration of our findings in light of adult models will beg questions as to whether there are differences in children, given their less mature control processes, fewer, less enriched long-term memories, and possibly greater reliance on the immediate sensory environment. The nature of this study – its small number of participants (typical for qualitative work) with a wide range of ages, coupled with the high level of individual variability in creative approach (as illustrated by the idiographic narratives) – will make it tough to answer such questions. At this stage, we will mostly concern ourselves with broad consistencies between adult models and current findings. A fine-tuned analysis of differences between children and adults, for example analysing verbal reports of their approaches when completing the same creative task, would make a fascinating future study.

Over the last few years, several researchers from disparate fields, including computational modelling, neuroimaging and cognitive psychology have presented models which ascribe a central role to the ability to shift between processes which are controlled (though variously called 'analytic' 'persistent' or 'highly filtered') and those which are spontaneous ('associative', 'flexible' or 'low filtered'). The ecological validity of such models is bolstered by evocative similar accounts from real world creatives.

Pringle and Sowden's 'Mode Shifting' model (see Figure 3.5 below) portrays a 'shifting mechanism' (proposed to be the 'salience network') which alters the dominance of either associative (equivalent to 'spontaneous') or analytic (equivalent to my 'control') modes of thought. Their 'mode shifting index' seeks to quantify both the frequency of shifting and the metacognitive awareness of it using self-reports.

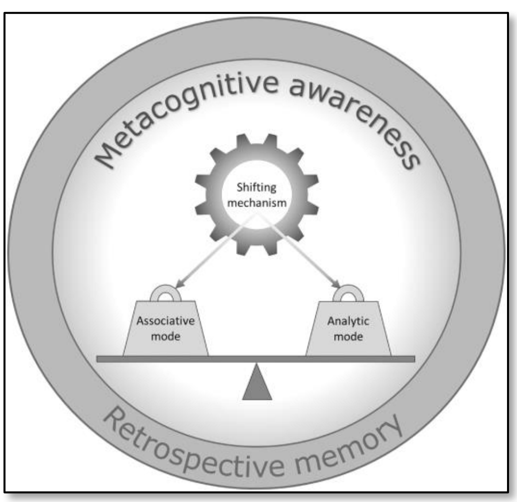


Fig. 3. 5 Pringle & Sowden's Mode Shifting framework (2017b).

The researchers emphasise that, although associative and analytic modes sometimes act in competition, they can also work cooperatively, so should be seen as a balance. They also stress that the need to shift may vary according to context and domain. Both of these accounts chime with children's descriptions, particularly in the sub-themes of the balance processes, which reflect both the 'balancing act' of spontaneity and control and the 'controlling of the control' which modulates the balance in response to contextual demands.

Chrysikou and team's 2014 'Matched filter hypothesis' is based on a synthesis of evidence from situations in which complex cognition (of which creativity is an example) does not benefit from greater cognitive control. Their model (see Fig. 3.6), which seeks to give a developmental account of the role of the prefrontal cortex (the seat of cognitive control), incorporates both trait (organism) and state (task) components to the flexible modulation of control. Their model suggests that the "optimal level of cognitive control is task-dependent, with high levels of cognitive control best suited to tasks that are explicit, rule-based, verbal or abstract, and can be accomplished given the capacity limits of working memory and with low levels of cognitive control best suited to tasks that are implicit, reward-based, non-verbal or intuitive, and which can be accomplished irrespective of working memory limitations" (Chrysikou et al., 2014, p. 341).

The account from children suggests that the determination of this 'optimal level' might operate not just at the broader task level but at a more granular level, within tasks and over very short time periods. For example, several of Lexy's responses touched on her relationship with distractions, which often involved moment to moment rebalancing between the openness needed to see the possibilities they might offer ('when my cat walked past I…thought cheetah's in the cat family so I wanted to draw that') and then the discipline to rule them out ('If I heard the

beeping…I might start drawing a car on water…I didn't do it because I reminded myself').
Children's accounts also point to examples of when this optimal level might not be reached, either through an excess of control (e.g., Kitty's post mortem realisation of the many opportunities she had missed to take a more open, less controlled approach) or too much spontaneity (e.g., Roxy's description of untapped idea overload leading to failures of evaluation, 'They were all zooming around and I was just yeah maybe I was a bit indecisive').

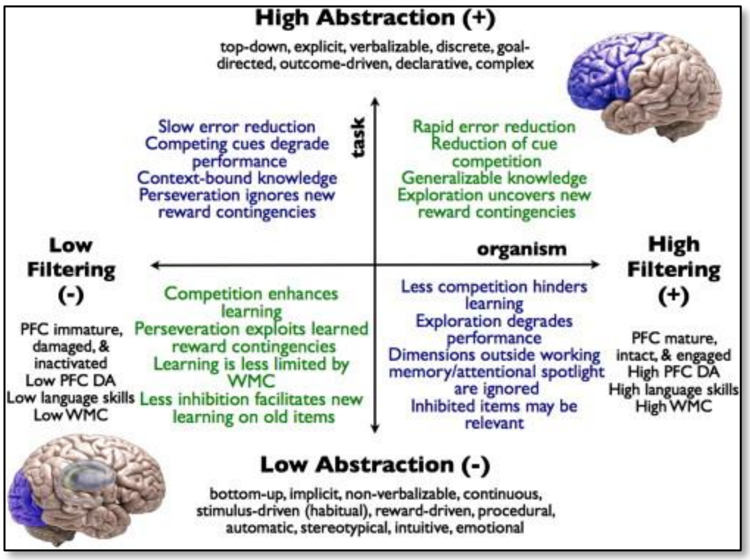


Fig. 3. 6 Chrysikou et al.'s Matched filter hypothesis (2014)

From a different approach, computational modellers have devised models which attempt to unify evidence from divergent and convergent thinking studies in creativity research. Some of these also involve the imposition of some kind of metacontrol 'balance system' in order to keep control and spontaneous processes in check. Mekern et al.'s 'Metacontrol state model' (2019), like the matched filter model, incorporates both state and trait differences. It proposes that individuals differ in their creative tendencies (due to social, cultural, and genetic predispositions), such that some people naturally operate using a more controlled approach and some a more spontaneous one. In addition, particular tasks and situations will make different demands on the balance between control (persistence) and spontaneity (flexibility).

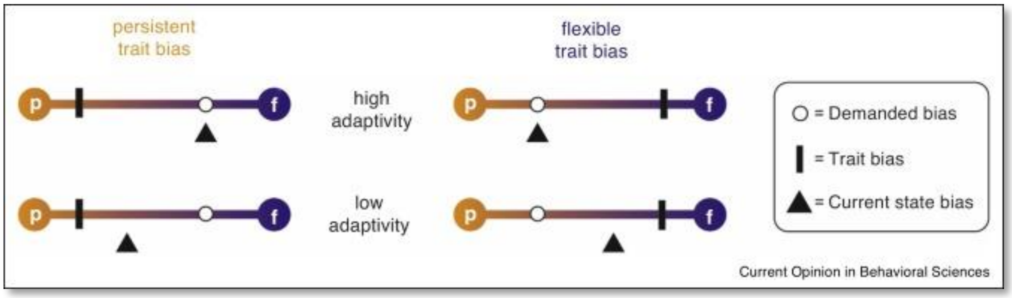


Fig. 3. 7 Mekern et al.'s metacontrol state model (2019).

Again, this model has much in common with the current analysis. The idiographic narratives show that some children e.g., Snowy, tend to a very spontaneous creative approach while others e.g., Alex, are controlled by default, while others, e.g., Lexy and Imagination Creation, show much more moment-to-moment flexibility in their approach. Most children changed the emphasis put on control processes at different points in the task or when operating in different domains (e.g., moving from preparatory planning to drawing). There are also some differences between this model and the current analysis; in particular, the idea of persistence (defined as 'in-depth exploration of only a few categories or perspectives'; Nijstad et al., 2010) was not something that really appeared in children's accounts. While 'persistence' describes a determination in sticking with a particular approach or ideational path, children's reports of control processes were more concerned with ruling out ideas that didn't pass muster and moving on, as opposed to tenaciously burrowing through them and onwards to better ones. Perhaps this sort of industrious, unwavering focus is simply too demanding for children's less developed control systems.

A final model with resonance for the current study is again derived from computational models integrating divergent and convergent thinking processes but here with a neuroscientific twist, proposing the brain basis for different approaches. "The key idea is that flexibility is promoted by weak activation of the DLPFC (dorsolateral prefrontal cortex) and T/PC (temporal/parietal cortex) together with a strongly activated left IFG (inferior frontal gyrus), whereas persistence would be characterised by the opposite pattern" (Zhang et al., 2020). Again, the similarity with children's accounts is notable, though the words are very different: 'At the back yeah they're the crazy bits but like here (forehead) yeah like here is sensible and if ever I want to have sensible ones (I have to) push go back go back' (Imagination Creation, age 9).

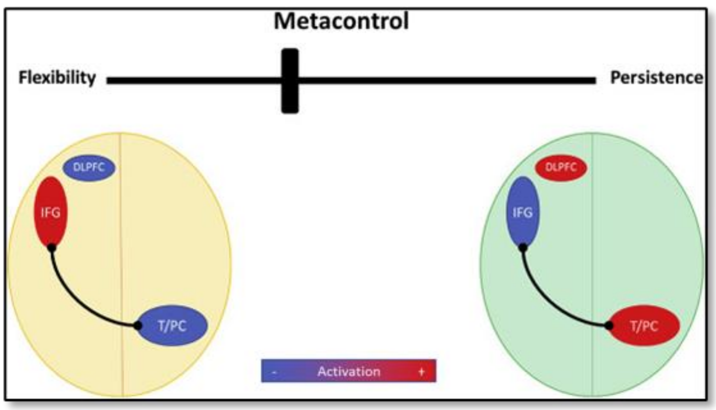


Fig. 3. 8 Zhang et al.'s proposed neurocognitive framework for metacontrol of creative cognition, 2020.

All these models, in common with findings in this study, alight on the idea that cognitive control is not straightforwardly beneficial, but that its benefits accrue when it is used in a manner appropriate to the task in hand. In addition, most share a characterisation of individual differences both in the underlying tendency to approach creativity in more spontaneous or more controlled ways and in the flexibility to modulate this tendency.

The idea that creativity is characterised by an ability to flexibly shift between extremes of approach seems also to be understood by real world creatives. The playwright Stephen Beresford, interviewed about Ingmar Bergman's drama, 'Fanny and Alexander', observed that "People often characterise the story as the conflict between the wildly imaginative Alexander and the despotic controlling bishop. I think what they forget is that, for an artist, both things must be alive. You have to be wild and freewheeling and imaginative as an artist, but you also have to have ruthless rigid control and discipline.” (Interviewed by Tom Sutcliffe on Start the Week; BBC Radio 4, 2018). The iconic actor and comedian John Cleese echoes this, “Creativity” he says “is a way of operating. We need to be in the open mode when pondering a problem, but once we come up with a solution, we must switch to the closed mode to implement it” (‘Cleese on Creativity’ lecture, 1991).

Limitations

Although efforts were made to ensure the naturalism of the study, there were still limits. Only two domains of creativity were offered and all but two of the children chose to draw, possibly because the performance aspect of storytelling made it daunting. In the drawings, further constraints were put on children by the materials, the setting, and the need to include the sparks. This might have affected their intrinsic motivation, an aspect of the creative process that is potentially very important but hard to assess in a scientific study (Amabile, 1982b, 1983). The children appeared to be well motivated in their creative endeavours, but the task was nonetheless imposed. Related to the issue of naturalism is the fact that the children were being filmed. Again, all but one of them (one girl said that the video made her feel uncomfortable so only audio was used) seemed to be relaxed with being recorded, but a feeling of being observed might have affected their process in unknown ways.

The use of introspective methods runs the risk of verbal reports being confabulated. Efforts were made to bring rigour to the data with the use of the ‘7Cs’ checklist. These checks aimed to address both the accuracy (e.g., confirmation, contradiction) and the validity (e.g., confidence, consistency) of the data. More broadly, the validity of introspective reports came through the specific and particular approach to questioning.

The level of creativity achieved in their products was not assessed. Beyond the assertion that the children were all by definition engaged in the creative process because they produced something novel (using new ingredients to ensure work was not a simple facsimile of a previous work) and appropriate in that they met the goal in hand, there was no attempt to distinguish between highly creative and less creative work. This was quite deliberate in that to fairly assign value would have conflicted with other more important goals (lack of rules regarding time, domain) i.e., it would have been impossible to judge like with like - but it is a limitation in the analysis that we do not know if responses are reflecting a process underlying more or less successful creativity. In particular, our spontaneous-controlled balance beam model begs the question of whether being in different positions on the beam, or more or less agile in changing that position, is associated with more creative outcomes. To some extent, relating creative process to creative performance will be the job of the next chapter.

As mentioned, most (12 out of 14) children chose to draw. The subsequent analysis was thus largely an account of the creative process of drawing. Whilst there did not appear to be obvious differences in the processes described by the children who did storytelling from those who drew, the extent of individual differences in approach make it hard to be certain differences do not exist. In a similar vein, it should be noted that the majority (10 out of 14) of the participants were girls, something which, although there is no obvious evidence for it, might have influenced findings.

Conclusions and next steps

This study was motivated by two ideas: the first, which was bolstered by the experience of using DT tests in the study presented in Chapter 2, was that quantitative lab tests of creativity are insufficiently precise to reveal underlying mechanisms, since they can be completed in such a variety of ways. In addition is the concern that lab tests, in their excessive evocation of EC, might not represent the role of EC in the creative process in the real world. This idea pointed to the need to consider alternative tools in order to understand process. The second motivation was the sanguine view, boosted by seeing the quality and breadth of the responses they produced in those same tests, that children's verbal reports could potentially reveal important information about the underlying mechanisms that allowed them to arrive at those responses. This first-person account of the creative process in children is currently missing from the literature.

The findings of this study represented progress in answering one of the main research questions of the thesis, i.e., to what extent are there individual differences in the role that EC plays in children's creativity? The answer based on this evidence seems to be 'a great deal'. The analysis demonstrated wide individual variation both in the extent to which children naturally tended to a more or less EC-led approach in their creativity (i.e., a trait difference in spontaneity vs control) and in their ability to modulate the extent of that deployment (a trait difference in flexibility). In addition, there was much variation in the deployment of EC in creativity depending on context, task demands and domain (i.e., state differences). This variation raises important issues for later work when we will study the effect of improving EC on creative performance through an EC intervention (in Chapter 5). It seems likely that intervention effects will vary depending on children's tendency to use EC heavily or lightly in their creativity, though exactly how remains an open question: is a child with a 'low EC' approach likely to have their creativity bolstered by improving EC or might the improvement disrupt their preferred creative approach and so reduce their creativity? Or is a child with a 'high EC' tendency going to benefit from further EC improvements in augmenting their chosen approach – or might it tip them over into failures resulting from excessive control? We will address these questions in Chapters 5-7 which present quantitative, qualitative, and triangulated data from an EC intervention.

Addressing the second thesis question - does inhibitory control have a detrimental effect on children's creativity? – cannot be fully answered solely using data from the current study, since we have no measure of children's level of creativity. There are clues that inhibitory control had detrimental effects in some instances e.g., as described by the theme 'Creativity fails at the edges', but this theme also included reports of failures caused by excessive spontaneity. To get better traction on the question of the effect of inhibitory control on performance, we have two ways forward. The first is through studying the effects via the intervention study described above. The second involves bringing together the current study's accounts of process with data from the quantitative tests these same children completed earlier (in the *Bright Sparks* study in Chapter 2). Chapter 4 will now turn to this task of data triangulation.

Chapter 4. Bringing quantitative and qualitative data together

Introduction

In this chapter, I will introduce mixed methods and the rationale behind them, before outlining some of the epistemological and practical issues raised by attempts to bring highly diverse data sets together. I will present strengths and weaknesses of different approaches in general and introduce the specific 'third paradigm' approach taken here, one based on a set of principles drawn but distinct from its quantitative and qualitative counterparts. Different methods for practically combining the current data will be discussed and some of the problems illustrated with reference to some early unproductive attempts, before presenting the methods and findings from the approach finally chosen.

What are mixed methods?

Mixed methods (MM) are increasingly being seen, alongside quantitative and qualitative approaches, as 'a third major research paradigm' (Johnson et al., 2007, p.112; also see Creswell, 2009; Creswell & Clark, 2011; Hesse-Biber & Johnson, 2015; Morgan, 2007; Tashakorri & Teddlie, 2009, 2010). The adoption and discussion of MM (and related multimethod approaches) has seen significant growth in the last twenty years (Schwandt & Lichty, 2015). MM research refers, most simply, to the collection and combination of both quantitative and qualitative data to address the same research question (Johnson & Onwuegbuzie, 2004). Its chief motivation is a recognition that all methods have limitations and weaknesses and that combining different approaches "increases the likelihood that the sum of the data collected will be richer, more meaningful, and ultimately more useful in answering the research questions" (Preskill, quoted in Johnson et al., 2007, p. 121). The approach, for some, represents an enthusiasm and belief that science needs to progress beyond single method approaches, which are sometimes deemed insufficient. Small observes, "Dissatisfaction breeds creativity. Empirical researchers have been unhappy with the natural limits of conventional methods, including experiments that do not uncover mechanisms… Their efforts have given rise to a large, diverse literature that combines or integrates either data collection techniques or analytical approaches from multiple perspectives" (Schwandt & Lichty, 2015, p. 79). The methodological approach to any research depends on the questions being asked. At one extreme are questions which can only be answered qualitatively ('How did your first day at secondary school feel?'); at the other, are those demanding a quantitative approach ('How quickly can children react to a new visual stimulus?'). Our research questions here, which concern the contribution of EC to creativity, concern two constructs which are highly multifaceted, with performance in both depending on a range of situational, motivational, and emotional factors as well as cognitive ones. For these reasons - to gain better traction on complex interrelated dimensions - a mixed methods approach is deemed most appropriate here.

There is more than one rationale for the use of mixed methods and a huge array of design typologies (Creswell and Clark, 2011, suggest at least 15). In addition to the broad idea of enriching information through multiple perspectives, MM can be used to:

- Study causality at different levels of description (Johnson et al., 2017)
- Allow one approach to inform another (e.g., qualitative findings might inform better quantitative tests or quantitative results might suggest where to research in more depth qualitatively)
- Look simultaneously at product and process

- Cross-validate. Finding similar phenomena using very different approaches increases the likelihood that they are real (Creswell & Clark, 2011; Johnson et al., 2007; Tashakorri & Teddlie, 2010; Yardley & Bishop, 2008).

Epistemological issues

The question of how to bring the multiple perspectives of MM research together has no simple answer. It raises issues of both an epistemological and a practical nature and requires ‘navigation across a turbulent borderland’ (Hesse-Biber, 2015). Epistemic tensions (dubbed ‘paradigm wars’; Tashakorri & Teddlie, 1998; Teddlie & Tashakorri, 2008) have raised questions about whether quantitative and qualitative researchers have the necessary skills, tools and philosophical openness to engage with ‘the other side’. Purists believe that quantitative and qualitative approaches are fundamentally unmixable (Guba & Lincoln, 1989) being founded on different beliefs about the nature of knowledge, and debates about mixed methods approaches have raged more or less stormily for two decades (Creswell, 2009; Creswell & Clark, 2011; Hesse-Biber & Johnson, 2015; Tashakorri & Teddlie, 2009, 2010).

Before we get drawn too deeply into these debates, it is perhaps worth going back to some basics regarding this study. The goal is to understand the role that executive control processes play in children’s creative process and the mixed method proposition is that both quantitative and qualitative data can contribute valuable information to address this question. The shortcomings of both the quantitative approach – chiefly problems with psychometric tests of creativity - and of the qualitative approach – persistent questions regarding the validity and accuracy of verbal reports as cognitive data – have been discussed at length in Chapters 2 and 3. I have endeavoured in both cases to set conclusions in the context of conservative limits of how far we can reasonably extrapolate the respective data. The new challenge presented in this chapter therefore concerns the extent to which these data can be integrated, theoretically and practically.

I am not a methodological purist; in fact, I would argue that taking an oppositional stance to qualitative and quantitative approaches is, apart from being unhelpful, an inaccurate portrayal of their true nature. ‘Quantitative’ and ‘qualitative’ labels tag a huge array of methodologies and epistemologies (Midgley, 2006) with as much variation within type as between (Hammersley, 1996). Consideration of the epistemic basis of any data should be a component of any study, not only those which seek to combine data. ‘Pragmatism’, the foundation of the current approach (based on Morgan’s (2014) definition, outlined below), has many meanings even within the MM field. The pragmatic approach taken by many MM researchers (Creswell & Clark, 2011) focuses less on their own epistemological perspective and more on what is needed to best answer the research question (Hesse-Biber, 2015). According to Creswell and Clark, pragmatism is often associated with MM because it focuses on “the consequences of research, on the primary importance of the questions asked rather than the methods” (quoted in Hesse-Biber, 2015). The flexibility of pragmatists to countenance research from multiple perspectives, using all available tools has led some to caution of ‘interdisciplinary opportunism’ (Patai & Koertge, 1994), the suggestion that researchers who dabble in new fields do so in a random or uncritical way. Others suggest that pragmatism, although founded on firm philosophical ground (primarily stemming from the work of John Dewey; Hickman & Alexander, 1998), sometimes morphs so as to become synonymous with merely ‘practical’ or ‘expedient’, with insufficient consideration of the basis of knowledge (Hesse-Biber, 2015). What is billed as ‘methodological eclecticism’ in reality just represents ‘muddled thinking’ (Mutch, 2009).

With the aim of replanting pragmatism in healthy philosophical soil, Morgan has proposed a heuristic which moves "beyond dualistic thinking (e.g., deduction vs. induction, subjectivity vs. objectivity, idiographic vs. nomothetic conclusions) toward more practical choices" (Morgan, 2014, p. 70) whose epistemological position is nonetheless defined. The table below illustrates this new pragmatic paradigm.

A Pragmatic Alternative to the Key Issues in Social Science Research Methodology

	Qualitative Approach	Quantitative Approach	Pragmatic Approach
Connection of theory and data	Induction	Deduction	Abduction
Relationship to research process	Subjectivity	Objectivity	Intersubjectivity
Inference from data	Context	Generality	Transferability

Fig. 4. 1 Morgan's pragmatic approach to MM (2014, p.71).

Pragmatism is here characterised by critical flexibility, by a view that positions represented as binaries are better seen as ends of continua, and by a dynamism in viewing the research endeavour as an ongoing, recursive, and communicated process. Abductive reasoning shuttles between induction and deduction, as theories are tested by gathering data which in turn informs new theories and so on. The usual forced dichotomy between subjective and objective is similarly replaced with the notion of 'intersubjectivity' which is happy to assert "both that there is a single 'real world' and that all individuals have their own unique interpretations of it" (Morgan, 2014) and finally any absolute distinction between the specific and the universal is rejected, in favour of a critical approach which interrogates the extent to which any finding can be applied to other settings and circumstances (Morgan, 2014; Schwandt & Lichty, 2015; Yardley & Bishop, 2017). Within the framework of such an approach, it is acceptable to lean a little more towards a positivist approach in quantitative work and to a constructivist one in qualitative work (Creswell & Clark, 2011). The current research is theoretically grounded in the sort of pragmatic approach Morgan outlines. This still leaves open questions about the logistics and practicalities of bringing together disparate data.

Practical issues

There is an array of approaches used to bring together the data in mixed methods research (Creswell & Clark, 2011; Hesse-Biber & Johnson, 2015; Tashakorri & Teddlie, 2009, 2010). A key feature of any sound approach must be that it "maintains the integrity of both method and findings" (Sandelowski, 1995, p. 573). Some argue that the only way to do this is to keep different types of data and different types of analysis essentially distinct. For example, Mason's 'facet methodology' (Mason, 2011) positions the overall research question as a gemstone, whose facets each reflect different ways of seeing and different research processes. A fuller understanding of the research question comes not from trying to force facets together, but from responding to the way in which the different facets give "flashes of insight" (Mason, 2011, p.75).

The mosaic approach also stops short of full integration but is a step closer. In Johnson et al.'s 'causal mosaic', the image carried by the mosaic (i.e., the area of research under investigation) only appears when its constituent tiles are appropriately arranged (Johnson et al., 2017). The mosaic is produced by taking a pluralistic approach, which endeavours quite deliberately and with clear articulation of assumptions at each level, to seek evidence at different levels of description. The Bradford Hill guidelines for establishing causality in epidemiological and medical research which have been used for half century are an example of the mosaic approach (Hill, 1965; Johnson, 2017).

Inching closer to integration of data, the word 'triangulation' is frequently used as a shorthand for describing the joining together of qualitative and quantitative data. In its original meaning (from engineering surveys) triangulation is "a means to establish the location of a point from two other points of known distance" (Sandelowski, 1995, p. 571) - that is, it implies the existence of knowledge from which other knowledge can be derived. The cleanest type of triangulation involves different but complementary data on the same research topic being brought together (Morse, 1991); cross verification from quantitative and qualitative perspectives on the same topic make it theoretically possible to produce findings which are both generalisable and ecologically valid (Creswell & Clark, 2007; Fielding, 2010).

There are many types of triangulation design (e.g., see Creswell and Clarke, 2007 p.63; also, Teddlie & Tashakkori, 2008) which it is beyond the scope of this chapter to fully examine. Instead, within the broad triangulation framework, I will endeavour to explain the reasoning behind the specific choices made here.

Why triangulate data?

The first step in triangulation involves asking some key reflexive questions: what do these data tell me and crucially, not tell me about? What is the strength of, and how convincing is the claim? How can I make best sense of different forms of data in a way that is consistent with these previous questions? (Mason, 2017). The first questions have been dealt with in detail in previous chapters so the focus here is on the third. There are various possibilities:

- Following up similar themes in the different data sets (e.g., comparing whether children who have low inhibitory control in quantitative lab tests also give accounts in their qualitative interviews which suggest low levels of control)
- Generating testable propositions and asking them of different data sets (e.g., if the quantitative data show a child has high fluency coupled with high inhibitory control, then the qualitative data could be used to look at how she is achieving this difficult balance

according to her own report. Or the other way around: does a child who describes in her qualitative account a very spontaneous approach show evidence of high levels of fluency in quantitative lab tests?)

- Using different data sources to address a topic from different angles (e.g., at a higher level of description, do children who are at the extremes of the control / spontaneity continuum present distinguishable profiles of scores in lab tests of EC and creativity?)

Research questions

The findings of Chapter 3 showed that children varied a great deal in the quantity and quality of EC involvement in their creativity; also, that there were trait and state differences in their flexibility to shift between more and less controlled approaches. What those data alone could not tell us was whether there was any relation between the approach taken and the creative level achieved – bluntly: were there better or worse ways of 'doing creativity'? This is the first broad question that the triangulation will attempt to address. It is important to state at the outset that we would not expect simple cause and effect, e.g., that high inhibitory control will mean poor creative performance, because there are many, many other factors contributing to creativity – motivation, engagement, memory, knowledge, experience, sensitivity, openness and more. Even if inhibitory control plays an important role it is very unlikely to tell the whole story. We are looking at relative rather than absolute performance, tricky when comparing between rather than within children. Nonetheless, triangulation could give clues to such associations.

The model derived from the qualitative study proposes that there could be creative failure at extremes. Is there evidence of this from our quantitative results? i.e., do those children at the extremes of 'spontaneity' or 'control' as evidenced by the qualitative work show failures, as proposed, in value and originality respectively? Again, here we must acknowledge an obstacle, discussed in the earlier critique of divergent thinking tests: there is no explicit measure of value. The rater method of scoring might carry a small, inadvertent benefit here since raters are instructed to 'take into account their sense of originality and inventiveness of each response, in one holistic measure', making value to some extent implicit; though since this same score is also the measure of originality, distinguishing between these two will be problematic. In addition, the rater method of scoring was only used for the AUT. Despite the problems, triangulation could provide some tentative evidence to support the prediction of failure at extremes of spontaneity and control.

Additional questions deal with cross-validation between approaches; to what extent is EC or creative fluency as reported in qualitative interviews correlated with EC or fluency performance in quantitative tests?

Methods

Participants and data overview

The children whose qualitative and quantitative data will be considered for triangulation are all those from the qualitative study except one. Alexandra (aged 9) had an incomplete set of quantitative tests and is not included. The final sample is the remaining 13 children, who are fully described in Chapter 3.

The quantitative data available for triangulation are:

- EC scores: Flanker, Stroop, visual and visuospatial working memory
- Creativity scores: AUT, Just Suppose, TTCT Figural test scores

- Demographic data: age

Qualitative data:

- Individual level thematic analyses of interview data

First attempts

There is no right way to do triangulation and one of the challenges of mixed methods is that each study has unique combinations of data presenting unique complications (Creswell, 2009; Tashakkori & Teddlie, 2010). In learning about mixed methods, I have at times wished to see more of the reasoning behind the methods ultimately chosen and not just the fait accompli; it is with this in mind – a belief that there is value in openly sharing knowledge won from experience – that I will briefly outline some of the false starts to the process here.

The first attempt at triangulation involved using the qualitative data to make predictions about the quantitative results. I ranked each child as low/medium/high on inhibitory control, working memory and creativity measures from their qualitative report and classified them into terciles on all scores from the quantitative data, to arrive at similar low/medium/high categories. I then compared categories, awarding points for exact (e.g., high/high) or near (e.g., high/med) matches.

The results showed very poor prediction (close to and even below chance) for EC measures and somewhat better prediction for creativity measures, but the findings themselves are not really the main point for showing this. Through doing this analysis, I realised this was an example of 'muddled thinking' rather than methodological eclecticism (Mutch, 2009) or, worse, that its spurious precision was 'positivism dressed in drag' (Giddings, 2016). First, I had treated the

Code	Pseudonym		Inhibition		MATCH?			Working memory		MATCH?			Fluency verbal		MATCH?			Fluency figural	MATCH?
		Inhibition	Flanker	Stroop	Flanker	Stroo	Working	VSWM	VWM	VSWM	VWM	Verbal flu	AUT flu	JS flu	AUT	JS	Figural fl	Fig flu	
132	Snowy	low	High	Medium	0	1	high	High	Medium	2	1	high	High	High	2	2	medium	Medium	2
152	Ben Ten	medium	High	Low	1	1	low	Low	Medium	2	1	medium	Medium	Medium	2	2	medium	High	1
1312	Dave	low	Low	Medium	2	1	high	Low	High	0	2	low	Low	Low	2	2	medium	Low	1
221	Dooda	medium	Medium	Medium	2	2	high	Low	Medium	0	1	high	High	High	2	2	medium	Medium	2
264	Silky	high	Low	Low	0	0	high	Medium	Low	1	0	medium	Low	Low	1	1	high	Medium	1
2222	Lexy	low	Medium	Low	1	2	medium	Low	Low	1	1	high	High	High	2	2	high	Medium	1
312	Maria	high	Medium	High	1	2	high	High	Low	0	0	medium	Medium	High	2	1	medium	Medium	2
4112	Harriet	high	Medium	Medium	1	1	high	Medium	Low	1	0	medium	Low	Medium	1	2	medium	Low	1
4132	Imaginati	low	High	Low	0	2	high	Low	Medium	0	1	high	High	Low	2	0	high	High	2
4142	Betty	medium	Low	High	1	1	high	Low	Medium	0	1	medium	Low	Low	1	1	medium	Low	1
5322	Alex	high	High	Low	2	0	medium	High	High	1	1	lower	Low	High	2	0	low	Low	2
5632	Kitty	high	Low	High	0	2	medium	High	High	1	1	lower	Medium	High	1	0	medium	Medium	2
5642	Roxy	low	Low	Medium	2	1	high	Medium	High	1	2	medium	Medium	Medium	2	2	medium	Low	1
TOTAL SCORE FOR PREDICTIONS					13	16				10	12				22	17			19
Intra-construct scores			match = 11						match = 14					match = 20					

Code		Originality verbal		MATCH?			Originality fi	MATCH?		Figural st	MATCH	TOTALS PER CHILD			
	Verbal or	AUT orig	JS orig	AUT	JS	Figural or	Fig orig		Fig streng	Figstrength			out of ma	% correct by child	
132	high	Medium	High	1	2	medium	Medium	2	high	High	2	17	22	**77**	Snowy
152	medium	Medium	Low	2	1	medium	High	1	low	Medium	1	15	22	**68**	Ben Ten
1312	low	High	Low	0	2	medium	Low	1	medium	Low	1	14	20	**70**	Dave
221	high	Medium	High	1	2	medium	High	1	medium	High	1	16	22	**73**	Dooda
264	medium	High	Low	1	1	high	High	2	high	High	2	10	22	**45**	Silky
2222	high	Medium	High	1	2	high	Medium	1	high	Medium	1	14	22	**64**	Lexy
312	medium	High	High	1	1	medium	Low	1	medium	High	1	12	20	**60**	Maria
4112	medium	Medium	Medium	2	2	medium	High	1	medium	Medium	2	14	22	**64**	Harriet
4132	high	High	Low	2	0	high	Medium	2	high	High	2	13	22	**59**	magination Creation
4142	medium	Low	Medium	1	2	medium	Low	1	low	Low	2	12	22	**55**	Betty
5322	lower	High	High	0	0	low	Low	2	low	Low	2	12	22	**55**	Alex
5632	low	High	High	0	0	medium	Medium	2	low	Medium	1	10	22	**45**	Kitty
5642	medium	Medium	High	2	1	medium	High	1	medium	Medium	2	17	22	**77**	Roxy
				14	16			18			20			62	
		match = 14													

Key

(yellow)	Quantitative findings - ranked by sample, tertiles High to Low
(light blue)	Qual predictions - high, medium, low
(grey)	Do scores align? Perfect match=2, one step off (ie high/med or med/low) =1, no match=0
(blue)	Total possible match score per variable is 26. Chance would be 14.43 [3/9 chance of 2; 2/9 chance of 0; 4/9 chance of 1]. So range is 0-26
(green)	Intraconstruct scores, where applicable

Fig. 4. 2 Tables illustrating the first, naïve approach to triangulation

qualitative findings simply (yet inaccurately) as a validation of quantitative results. Second, I had strayed far from the actual qualitative analysis to a merely impressionistic assessment of EC and creativity. And third, I had failed to grasp that findings, even had they found perfect prediction of quantitative from qualitative findings could not, given their uncertain foundation, have improved understanding of the research question.

The second attempt, which I saw as the qualitative counterpart to a statistical Principal Component Analysis (PCA), was an attempt to delineate specific sub-groups of children who shared particular underlying characteristics in their creative approach. Again, starting with the qualitative interview data, I sought to define children according to the principal components of the creative process they described, beginning with their position on a control/spontaneity axis. The difficulty of this approach was in limiting analysis to this single dimension when there were many other factors contributing to the child's creativity, some of which I had experience of through seeing them in action. Sometimes it was these other features, which don't come into focus through the control/spontaneity lens, which seemed key to their approach e.g., Betty whose ideas come from a meticulous memory for detail, or Harriet who is very self-controlled and also has a passion for 'weird things', or Imagination Creation whose ideas were supported and inspired by his vivid mental imagery. In the end, then, the groups were led by control/spontaneity categorisation but with other features also playing a role. The table below shows the sub-groups derived from this analysis.

Group name	***Shapeshifters***	***Handbrakes***	***Freewheelers***	***Enthusiasts***	***Introspectives***
Group members	Imagination Creation	Alex	Snowy	Harriet	Betty
	Lexy	Ben 10	Roxy	Dooda	Maria
	Silky	Kitty		(Dave)	(Dave)
Characteristic features	Score highly on spontaneity but also exhibit at times high levels of control. They can and do show both approaches at different times or under different constraints. Some flex between them almost simultaneously (IC) whilst others shift according to perceived need (Lexy)	The handbrakes tend toward a high level of control, in association with low levels of spontaneity. Freestyling ideas is difficult for them because they are primed to reject before they even begin. NB Alex is a tricky case since his approach in different domains varies	Ideas are overflowing in this group, sometimes to an overwhelming extent. Ie they can have problems selecting from the abundance and sometimes don't see the wood for the trees. Ideas just seem to happen to them and can be provoked by the least prompt. They sometimes describe taking action to stop the incessant flow	The enthusiasts might be at risk of blockage from excessive control were it not for their love of new ideas. This openness can outweigh their sometimes stringent approach and mean that failures of originality can be averted	The introspectives are harder to read and are the most mixed bag. They tend towards control in how their creativity operates and are rather inflexible. Control is more trait than state - they don't know another way. They live in their heads rather than seeking the new or unexpected
Likely point of failure	None	Originality	Value	None (originality failure thwarted)	Originality

Fig. 4. 3 Subgroups derived from principal components of creative approach

Again, various problems were identified with this approach: as with the first attempt, it moved too far from the analysed qualitative data, making use of other data such as observations, field notes, impressions, which had not been properly explicated, thus undermining the qualitative work. From the point of view of triangulating results (a stage I did not proceed to, realising the flaws), the groups only contained 2 or 3 children covering a wide age and ability range - so trying to use the widely varying quantitative results to delineate group differences seemed a fruitless exercise – i.e., triangulation would not have added information, even if the sub-groups were accurate portrayals of creative types. In the end, I felt that this analysis, whilst possibly of interest to other research questions, was not an appropriate basis for triangulation to address the current ones.

Without a clear direction, mixed methods provide an almost infinite set of possibilities to explore (Hesse-Biber, 2015). The two attempts described share two key features which impaired them: a failure to stay close to the data and a failure to properly articulate research questions. The third iteration which follows attempts to address both of these shortcomings.

Final approach taken

In the analysis I finally settled upon, I set out to answer the following research questions:

- Is there a correlation between children's use of control, spontaneity, and flexibility in their creative process (as qualitatively described) and their age?
- Is there a correlation between children's use of control, spontaneity, and flexibility in their creative process (as qualitatively described) and their quantitative results in lab tests of EC and creativity?

- Is there evidence of creative failure, as measured in quantitative tests of creativity, at extremes of the control/spontaneity axis?

The first step was to rank each child on each of the three qualitative dimensions: control, spontaneity, and flexibility. This meant going back to the individual child's thematic analysis and assigning them a score (on a 1 to 10 scale) for each of these aspects, on the basis of the importance of each of those themes for them. For example, while all the children had some examples of spontaneous processes – ideas 'popping up' – for some this was a rarity, whilst for others it was the most prominent aspect of their descriptions. Flexibility was the hardest to rate, since the ways in which children were flexible were the most varied e.g., Imagination Creation was flexible on a moment-to-moment basis, whilst Betty was flexible over a much longer time frame and Alex was flexible in one domain but not in another. Scoring children in this way also raises conceptual problems. For example, is the more controlled child the one who notices a lot of distractions but articulates the fact that they have blocked them out or the one who doesn't even appear to notice them? So, this approach is by no means unproblematic. Nonetheless, on the basis of the scores, the children were then ranked on each of the three dimensions.

The quantitative data were also prepared for the triangulation analysis. To control for age differences, standardised residuals from age-predicted linear regression analyses were calculated for each EC and creativity variable. Although some sub measures did not show age-related change, the most consistent approach was to control for age for all variables. The next step was to enter all the rank scores from the qualitative results alongside the standardised residual scores for each EC and creativity variable as well as other demographic information and carry out Spearman's correlations on all relevant variables. The qualitative data are no longer being used to 'predict' or 'test' findings against the quantitative data, but rather both types of data are being considered on a par, with a simple question being asked about their correlation. This change of language represents a subtle shift in the methodological approach away from one in which quantitative data dominates by default. Finally, on this analysis, it should be noted that finding no correlation between qualitative and quantitative measures carries alternative possible meanings. It could mean that there really is no relationship between quant-measured lab EC and qual-measured real-world EC, it could mean that one or other measure is too noisy, or invalid, or it could mean that they are measuring different things. Interpreting such a finding is not straightforward.

To address the final question, that of potential failure at extremes, rank scores were used for both the qualitative and the quantitative data, to best tackle questions of relative performance, e.g., were the children who were most spontaneous also the most creatively fluent? Were those who were most controlled also the least creatively flexible etc.? The analysis, the results of which are presented visually, compares the four children ranked highest for spontaneity with the four ranked highest for control, with the predictions that those ranking highest for spontaneity in the qualitative analysis will be amongst those scoring highest for fluency, flexibility and originality in the quantitative tests, while those ranking highest for control in the qualitative analysis will be amongst the lowest scorers on these variables.

Findings and analysis

The first step of the analysis was to see if age was correlated with the rankings for spontaneity, control and flexibility derived from the qualitative analysis, to get a clue as to whether age-related changes (for example, in the development of EC) were driving differences. The findings showed no significant correlations between age and the qualitative dimensions.

	Spontaneity	Control	Flexibility
Age	-.19	-.14	-.15
	.523	.660	.627

Table 4. 1 Spearman’s correlations (and corresponding p levels) between qualitatively derived rank scores and age.

The qualitative rank scores were next compared with standardised residual scores on each of the lab tests of EC. Despite expectations of associations between the control dimension and measures of inhibitory control in the lab, no significant relationships with any of the lab EC measures were found.

	Flanker	Stroop	VWM	VSWM
Spontaneity	.36	-.04	.02	-.05
	.222	.892	.961	.866
Control	-.08	.37	-.46	.10
	.795	.212	.159	.738
Flexibility	.41	-.10	-.36	-.20
	.163	.748	.275	.517

Table 4. 2 Spearman’s correlations (and corresponding p levels) between qualitative derived rank scores and EC test scores

In the next step, the qualitative rankings were compared with the standardised residual scores on the three creativity tests. The results showed that spontaneity was significantly and highly correlated with scores for fluency and flexibility (but not originality) on the AUT, but not with the other creativity tests. Control rankings, by contrast, were negatively correlated with fluency and originality (but not flexibility) in the Just Suppose test. Correlations between control rankings and AUT fluency and flexibility were also negative and close to the significance threshold of .05 (.067 and .051 respectively) and it is notable that out of 9 correlations, 7 were negative. The probability of this number of negative correlations happening by chance, under a simple binomial distribution, is .070. Flexibility rankings showed a similar pattern to spontaneity, with positive correlations with fluency and flexibility on the AUT and no other significant correlations. It is notable that only the verbal tests showed any significant correlations; the figural tests showed no evidence of a relationship with any of the qualitatively derived dimensions. The tables included here involve multiple comparisons and with the small participant numbers involved, no attempt was made to correct for these multiple comparisons. This should be borne in mind when interpreting the reported significance of relationships.

	Just Suppose			AUT			Figural tests		
	Flu	Flex	Orig	Flu	Flex	Orig	Flu	Orig	Strength
Spontaneity	.29	.40	.28	.77**	.75**	.18	.32	.37	.53
	.332	.176	.353	.002	.003	.550	.284	.213	.065
Control	-.64*	-.49	-.60*	-.52	-.55	.02	-.23	.08	-.47
	.017	.086	.032	.067	.051	.946	.460	.792	.103
Flexibility	.15	.25	.15	.67*	.59*	-.07	.21	.28	.30
	.626	.419	.635	.013	.032	.814	.495	.364	.329

Table 4. 3 Spearman's correlations (and corresponding p levels) between qualitatively derived rank scores and creativity sub scores, n=13. Flu=fluency. Flex=flexibility. Orig=originality. Strength=overall creative strength. * significant at .05 level. ** significant at .01 level

An alternative way of looking at these data is to start with the behavioural outcome (the lab test product) and compare qualitative strategy (the reported creative process), i.e., begin with the quantitative and then look at the qualitative findings: was there evidence that children who achieved the same test scores did so by similar means? The illustrations below are for originality in the AUT and in the figural tests, two measures which showed no significant overall correlation with qualitative rank scores. There were four children who, by chance, all scored the same for AUT originality (a score of 3, just above the mean of 2.93). The figure below (Fig. 4.4), in which each coloured line represents a child, shows their relative positions on axes of spontaneity, control and flexibility (with highest scores on the outside). It suggests that, although their output was equivalent, the process for producing it was different for each of them. It also demonstrates how considering only product measures presents only a partial picture.

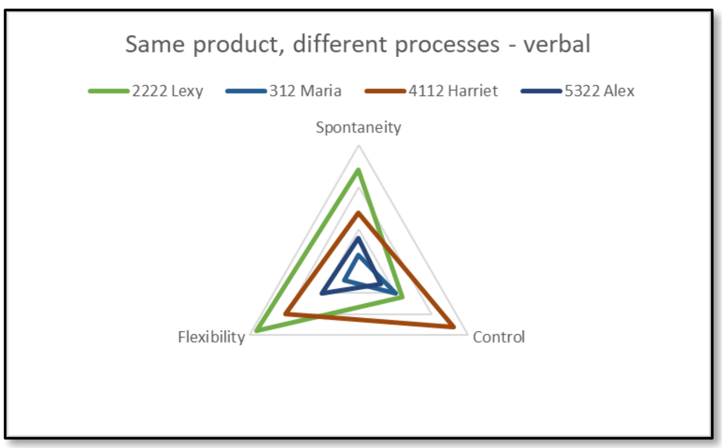


Fig. 4. 4 Four children who all scored 3 for originality in the AUT took different approaches to their creativity.

A similar finding is shown below (Fig. 4.5), this time for originality in figural tests. Again, some children achieved identical scores for this measure: three children all scored 4, just below the mean of 4.15. Once again, their approaches appeared distinct.

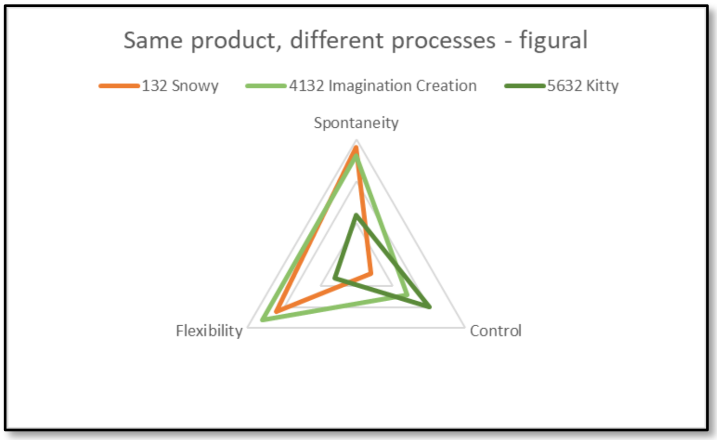


Fig. 4. 5 Three children who all scored 4 for originality in the figural tests took different approaches to their creativity.

The final set of analyses considered the difference between performance of children who operate at the extremes, comparing those ranked most highly for spontaneity with those ranking most highly for control on the creative indices. Findings are presented figurally (Figs. 4.6 and 4.7), with red spectrum colours depicting highly spontaneous and blue spectrum highly controlled children. The results show that, for fluency and flexibility, all four 'spontaneous children' outperform all four 'control children' in all these measures across both verbal and figural tests.

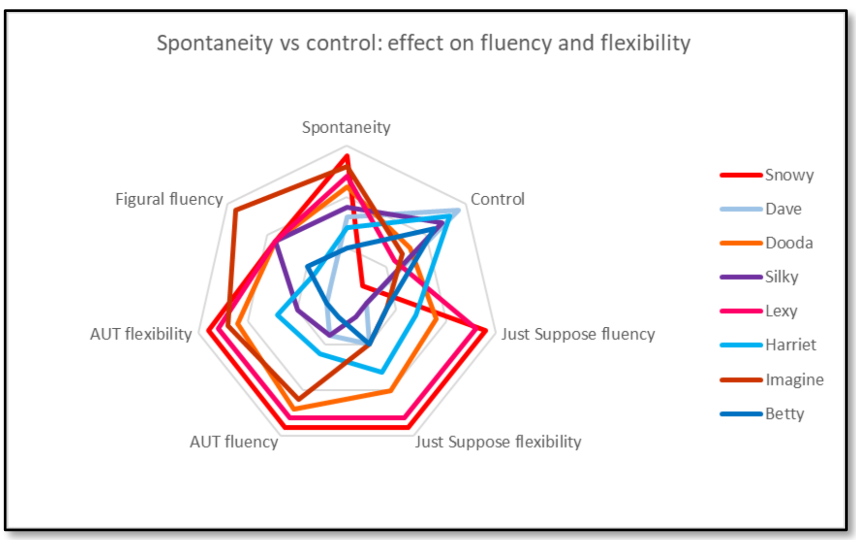


Fig. 4. 6 Comparison of the four children ranked highest for spontaneity (shown in red spectrum colours) with the four ranked highest for control (shown in blue spectrum colours) on measures

of fluency and flexibility across verbal and figural tests. Note that the measures of 'Spontaneity' and 'Control' are qualitative rankings while the others are quantitative scores.

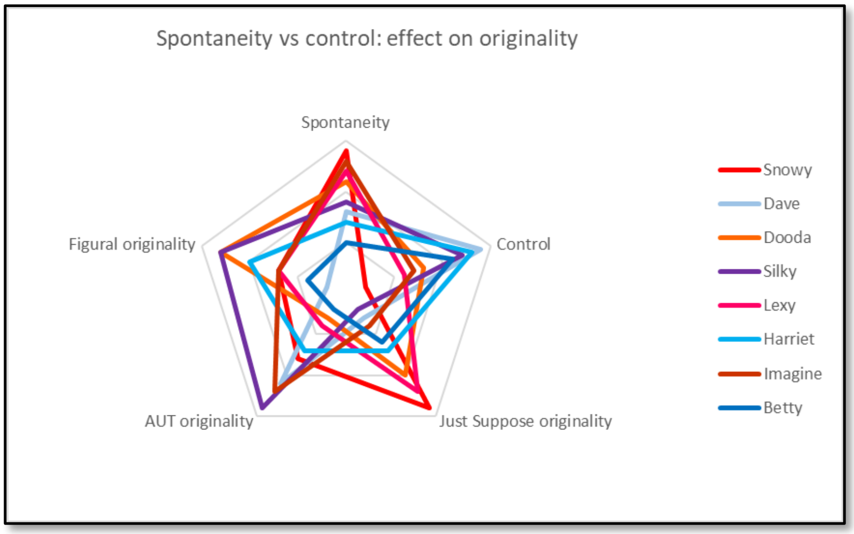


Fig. 4. 7 Comparison of the four children ranked highest for spontaneity (shown in red spectrum colours) with the four ranked highest for control (shown in blue spectrum colours) on measures of originality across verbal and figural tests. Again, note that the measures of 'Spontaneity' and 'Control' are qualitatively derived, while the others are results from quantitative tests.

Turning to a similar comparison with originality scores, the results are more mixed. In the Just Suppose test, the same pattern was seen as with fluency, i.e., the spontaneous children outdid control children. But in AUT and figural originality, there was no clear delineation between the two groups.

Discussion

This triangulation analysis sought to maximise the value of quantitative and qualitative data by using the combined data to address new questions. Specifically, it investigated whether the qualitative assessment of relative degree of control, spontaneity, and flexibility that children deployed in their approaches to creativity associated with their performance in quantitative tests.

The goal was to gain traction on the question of whether there are better or worse ways of going about creativity – i.e., as opposed simply to *different* ways of going about it. Although the results were not consistent across all creativity tests (with figural tests in particular failing to show any notable relationships with any qualitative dimension), the pattern was broadly in line with predictions: namely, greater spontaneity tended to be positively associated with creativity variables while greater control tended towards a negative association. There were no significant correlations found between qualitative measures and lab tests of EC. And while there was no evidence of failure at extremes of spontaneity, there was some evidence of failure, in fluency and flexibility, at extremes of control.

What did we learn about control?

The expectation had been that triangulation findings might help simplify the next stages of research. For example, a possible outcome was that qualitative and quantitative findings would be tightly related so that ‘control’ as conceived through qualitative work would approximate ‘control’ as measured in lab tests. This would make potential further work much simpler: the qualitative work would essentially have served to validate the quantitative tests as representing the processes of interest, allowing lab tests (which are much more practical for larger studies) to be used as a shorthand for children’s likely creative approach. This expectation was not realised; there was no correlation between the qualitative dimensions and performance in any of the EC tests.

There are various possible explanations for this lack of correlation:

- Control as presented qualitatively describes a much broader set of activities than the more granular and specific processes represented by inhibitory control measures in lab tests.

There are many other factors at play between these levels of description which is why no evidence of a relationship is seen (Astle & Scerif, 2008).

- These particular tests of inhibitory control did not get to the aspects of control most salient to the control deployed in creative work i.e., selective attention (Flanker) and cognitive inhibition (Stroop) are simply not the most relevant of the many aspects of control (Nigg, 2000).
- Children deploy control differently in different contexts. EC is sometimes even characterised by adaptability to different situations and contexts (for example, in the 'matched filter hypothesis' described previously; Chrysikou et al., 2014).
- Poor inhibitory control is easier to define than good inhibitory control. While poor inhibitory control is evident and can be articulated ('I was distracted by the noise', 'I just couldn't help blurting it out'), good inhibitory control might be more obscure, even to the person whose brain it is activated in. For example, a child might be so effective at blocking out potential distractions that they are unaware of them. To make things still more complicated, we could even say that the 'goodness' of good inhibitory control is not synonymous with strength of control but rather lies in the ability to apply strong or weak control as required by the context (Amer et al., 2016; Storm & Patel, 2014).

What did we learn about the creative process?

Another purpose of triangulation was to provide evidence regarding the relative effectiveness of different creative approaches (i.e., the extent to which the creative process is control-led, spontaneity-led or flexible) in achieving creative success. First, we examined the possibility that control processes would be negatively associated with creativity measures. While most of the correlations were indeed negative, they were not consistently statistically significant – for fluency and originality in the Just Suppose test, they reached significance, while in the AUT (fluency and flexibility) they did not. Associations with figural sub-scores were all weak and not significant. The general notion that the influence of control on creativity can be a negative one aligns with evidence from other sources (Beaty et al., 2016; Carson, 2011; Chrysikou et al., 2014; Limb & Braun, 2008; Radel et al., 2015) though the dissimilarity of findings for different creativity tests still needs explaining. Just Suppose is a task based in an imaginary situation ('Imagine that clouds had strings attached to them…') whereas the AUT is based on an everyday, familiar object (a pencil, a plastic bottle) which perhaps makes it easier to solve through a controlled, strategic approach. As Gilhooly and colleagues showed through protocol analysis, there are several ways to produce AUT answers which involve deliberate strategy rather than reliance on memory or the immediate sensory environment (Gilhooly et al., 2007) – that is, through controlled approaches. For the Just Suppose task, by contrast, it is perhaps difficult for those with a highly controlled approach to make the necessary imaginative leap to get going; there are fewer paths to strategic approaches to answers when operating in an ill-defined problem space (Dietrich, 2018).

By contrast, spontaneity and flexibility were both highly positively correlated with fluency and flexibility in the AUT but showed no significant relationship with any sub-scores in Just Suppose or the figural tests. Again, the general notion that flexibility in particular is positively associated with creativity is supported by previous research (Nijstad et al., 2010; Vartanian et al., 2020) though the reasons for the inconsistencies in different tests are not immediately obvious. Perhaps the different starting points of divergent thinking could also have been relevant here; an ease with tapping into memory and sensory processes might have been helpful in the concrete world of the AUT but could have foundered more when confronted with an imaginary scenario. The account of the role of EC in creativity might be one that crucially depends on the details and specific requirements of each task. This puts the onus on researchers to specify and characterise creativity task types and indicate the relevance of EC to each.

Whilst there is some evidence that particular approaches to creativity might generally be successful, it is important to remember that there is a great deal of individual variation, as evidenced by very diverse approaches which can result in identical scores. In fact, there is a danger that looking at overall results can obfuscate individual-level information. This can be a problem with certain types of mixed method triangulation (Bryman, 2007; Hesse-Biber, 2010) and a similar phenomenon has also been described in neuroimaging experiments, when the high level of noise in the data is reduced by averaging results from a large number of trials across different participants. Some have pointed out that this can obscure rather than reveal the processes underlying behaviour. “A wealth of relevant information is hidden, and potentially invalidated, when data are averaged across subjects…we consider between-subject variance in brain function as data rather than noise” (Seghier & Price, 2018, p.517). Using group-level results such as averages can mean that results, whilst true for the group, are not true for any individual within it. “In typical multisubject neuroimaging studies, tasks are assumed to be performed in the same way… however, many tasks are unconstrained, allowing subjects to adopt their own strategy…the estimates from the group might not actually describe anyone well” (Seghier & Price, 2018, p. 519). They argue that much greater attention should be paid to individual strategies and approaches, an observation which chimes loudly here, for an evolving model which suggests there are many means by which creative goals can be achieved i.e., that in extremis, every individual might have their own unique approach.

A proposed model

A model of creativity which emerges from the literature is one which involves both control processes (also called evaluative or analytic processes) and spontaneous (also called associative or sensory) processes (e.g., the Geneplore model; Finke et al., 1992; Finke, 1996; Ward et al., 1997). In this sort of model, control and spontaneous processes are both essential components since the creative process involves a recursive shuttling between the two. By implication, the system also requires flexibility to move between approaches.

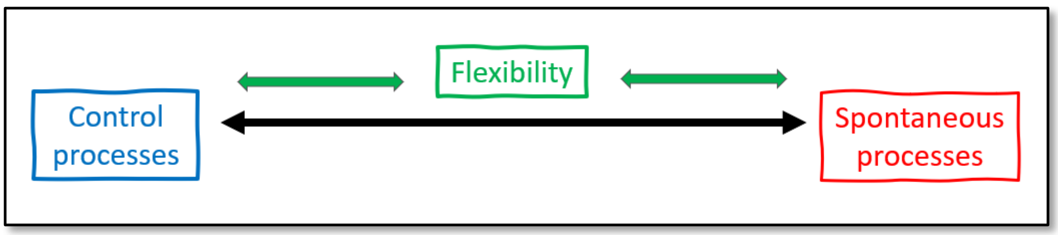


Fig. 4. 8 Model 1. Control and spontaneity are both needed for creativity, as is the flexibility to move between them.

An alternative model proposes that creativity can be achieved through diverse means, with the approach taken depending on multiple factors, such as domain knowledge, memory, and motivation. The combination of factors mean that for any creative task, some favour a more controlled, strategic, analytic approach and others an open, spontaneous one, steered by memory and senses. An example of this sort of model is Nijstad and colleagues' dual account which suggests that different individuals favour either 'flexible' or 'persistent' approaches (Baas et al., 2013; De Dreu et al., 2008; Nijstad et al., 2010). This model, and the other models considered, is presented as static, but ideally we would also want to consider such a model within a developmental framework.

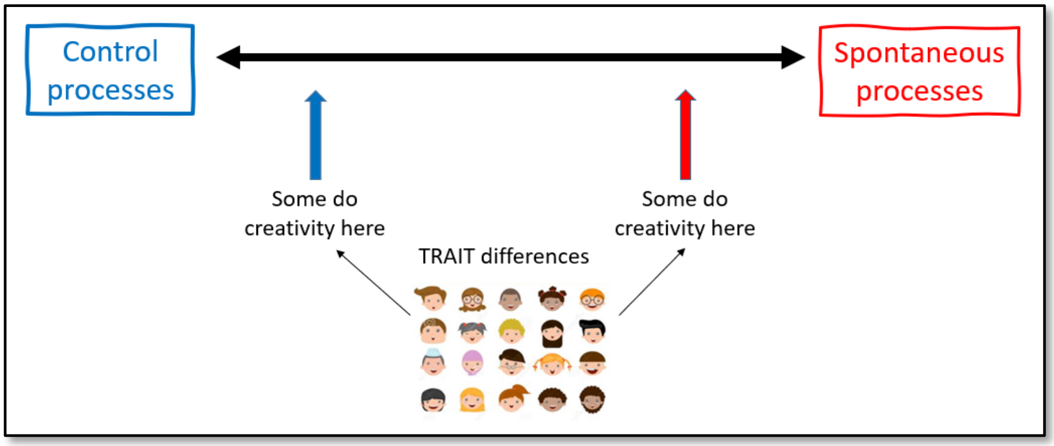


Fig. 4. 9 Model 2. There are many distinct creative approaches, determined by the personality and temperament of the child.

The findings from the current research suggest a third possible option, which combines elements of both models 1 and 2. Key features of this new model are:

- Trait differences suggest that individuals tend to favour different creative approaches - some more controlled, others more spontaneous
- These trait differences are not completely fixed and can be moderated by state differences; changes in domain, context, task demands, level of constraint, mood and more can change the relative emphasis on control or spontaneous processes
- Individuals who operate at the extremes run the risk of failure – in originality if stuck at a control extreme, and in value if stuck in spontaneous mode
- Flexibility remains, as in model 1, a key component since it acts as a protective buffer against becoming stuck at control/spontaneity extremes and allows adaptation to the demands of different tasks, contexts, and constraints
- By extension, this means that the most flexible individuals are best equipped to be the most creative

- Many other factors (e.g., knowledge/expertise, perceptual sensitivity, attitude to risk, tolerance of ambiguity, openness, memory, motivation) also contribute to the creative process. So, while an individual's position on the control/spontaneity continuum and their level of flexibility is important for how likely their creative success, it is by no means fully predictive of it

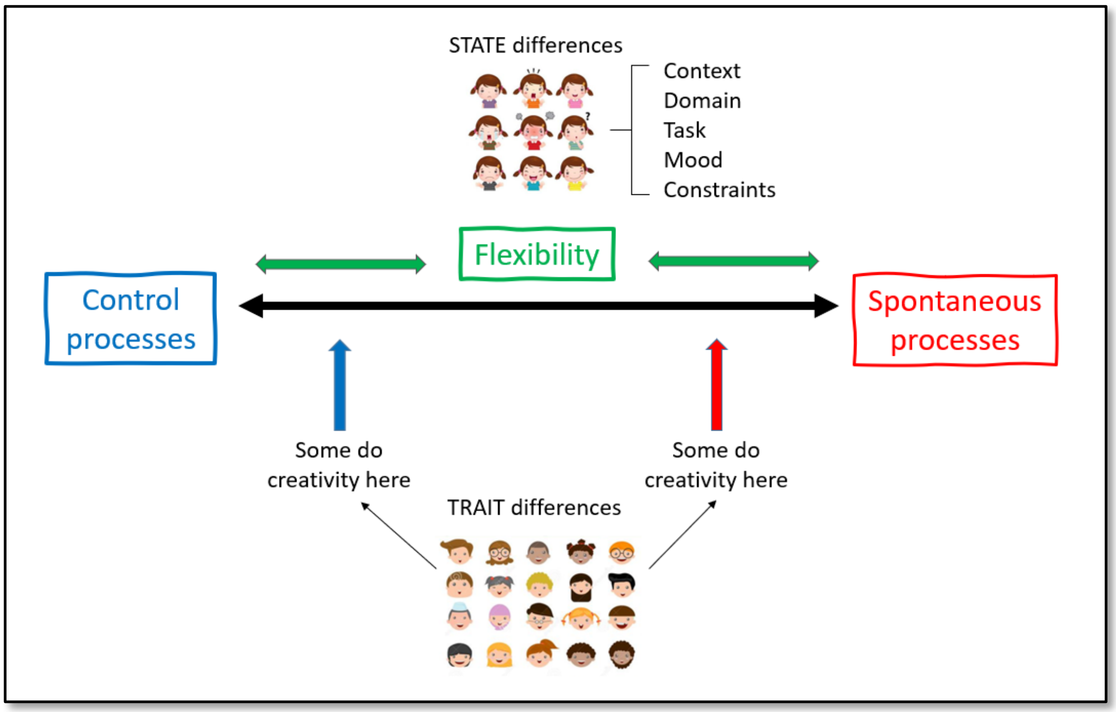


Fig. 4. 10 Model 3. Proposed model for creativity based on the current work. Trait and state differences determine children's position on the control/spontaneity axis and their level of flexibility determines their ability to shift that position.

In the following chapters, this model will be considered in the light of an EC training intervention. There are many ways in which such a training could influence creative outcomes (assuming successful training and some degree of transfer – both of which assumptions will be scrutinised in Chapter 5). For example, training macro-level flexibility, i.e., improving metacognitive switching ability, should be advantageous to everyone since flexibility is positioned as straightforwardly beneficial to creativity. By contrast, training specific aspects of inhibitory control (e.g., training children to ‘stop and think’ before responding) could have negative consequences for those who are already operating at a control extreme and have insufficient flexibility to adapt their approach.

Limitations

The exercise of triangulation presented several challenges, many of which have already been acknowledged - and some of which are an inevitable result of bringing diverse data together. Many assumptions were made, including that the creative process as described qualitatively (in a task completed at home, without time limits and with freedom from many constraints) is equivalent to that in action in quantitative tests (in tasks completed in a lab, with many imposed constraints of time, domain, materials and more). Since the qualitative findings show that the creative process can be affected by changing domains, constraints and so on, this assumption is undoubtedly problematic. This limitation will be addressed in subsequent studies by yoking the quantitative and qualitative research more tightly together, so that like can be more meaningfully compared with like.

While the best-case scenario of triangulation is mitigation of the weaknesses of single methods alone, the worst case is their amplification. While separate findings can be contextualised within the expectations and limits of their respective frameworks of study, in triangulation, findings must in some respects be hardened and taken out of context to be compared with others. Within the quantitative study, for example, much has been said about the problems with AUT originality scoring – but for triangulation, the scores have simply to be used as they are, without question. Similarly, in preparing qualitative analysis for triangulation, subtle shades must be repainted as bold colours e.g., in order to quantify which of two spontaneous children is the more spontaneous. These problems are exacerbated by the absence of clear, external procedures for validation – a side effect of the fact that every mixed methods study is unique. This means that there is often, as here, only one person with full familiarity of both sets of data - one reason why transparency is so essential in mixed methods research. I have tried to be as candid as possible here about the processes involved and their imperfections. Transparency in this study involved reporting false starts in the analysis, respectively: i. deriving rankings of qualitative data equivalent to the quantitative variables and seeking to correlate rankings in both versions of each variable; ii. grouping children according to a small number of analysed and observed dimensions within the qualitative data, analogous to a PCA; before deciding upon iii. ranking the children according to stricter criteria of qualitatively analysed data relating to the three dimensions of control, spontaneity, and flexibility, then relating these ranks to rankings of the quantitative variables. Even within this third approach, there remained the tension of relying on parametric or non-parametric statistics – i.e., tension arising through the fact that while qualitative work presses for depth and consequently has small participant numbers, quantitative research depends on larger, representative samples. When alerts are sounded as to the risks of spurious findings through multiple comparisons or non-significant associations are found, it is not obvious whether normal quantitative rules or alternative, more flexible interpretations should prevail.

Conclusions and next steps

In this chapter, the quantitative data from Chapter 2 and the qualitative data from Chapter 3 were brought together to seek new insights. With the caveat of the several limitations already described, there were four headline findings: first, the predictions about the benefits of spontaneity and the harms of control were at least in part born out, with evidence of (respectively) positive and negative correlations with outcomes in creativity tests. Second, there was also evidence of the predicted failure at the extreme of control. Third, there was evidence that different creative means could result in identical products (i.e., test scores), suggesting both that there is no simple answer to the ‘best’ way of going about creativity, and that any mechanistic model must be flexible enough to sanction multiple approaches. Finally, there appeared to be no correspondence between the broad level ‘control’ asserted in qualitative data and the more narrowly defined control measured in lab tests, a finding to be carefully considered in designing tests and procedures for an appropriate EC intervention.

The rationale for the EC intervention, which will be the subject of Chapters 5 – 7, is that it will allow us to see, at the individual level, what happens to children’s creativity when their level of EC is increased. Looking at individual change is important given the large number of other factors, also varying between individuals, which contribute to creativity. By trying to keep these other factors constant, but manipulating EC, any causal claims about ensuing changes are potentially strengthened. More intriguingly, by nesting a qualitative study within the intervention, we can endeavour to map the creative approaches of individuals, about whom we can then make predictions regarding the effect of the intervention. So, the levels of question regarding the intervention are first, does EC training have any impact on creativity? If it does, does the impact differ between individuals? If it does, can that differential impact be attributed to differences in creative approach? And finally, if it can, is it possible to accurately predict the impact at the individual level? By the end of Chapter 7, the goal is to provide solid answers to all these questions.

A final musing, as we emerge from the sometimes-bewildering process of triangulation, is to remember that really getting to grips with any complex issue is almost sure to involve integrating multiple viewpoints and perspectives, methods, and analyses. We need to become comfortable with straddling boundaries and being at ease in a new liminal space. “Creativity will never be fully understood using the traditional scientific approach,” according to one of the field’s most esteemed scholars (Runco, 2008, p. 93). And according to another (and paraphrasing the classic quote from the movie ‘Jaws’), “To capture the mechanisms of creative thinking, we’re gonna need a bigger boat” (Dietrich, 2015, p.40).

Chapter 5. Does training executive control affect children's creativity?

A mixed methods, school-based intervention study

Introduction

In this chapter, the rationale for an EC training intervention will first be outlined, including explanation of how studying within-individual change over time potentially reduces some of the identified problems with creativity tests. The potential for cognitive transfer – the tendency for training one skill to improve performance on other skills – will be discussed, as well as some methodological issues raised by efforts to evaluate programmes designed to improved EC. The specific requirements for an appropriate EC intervention here, and the difficulty finding programmes which meet those requirements, will be outlined, before the methods and procedures used here are presented. Results will be broken down into sub sections addressing specific research questions and the discussion will end with a consideration of what the results mean for the evolving model of the role of EC in the creative process.

Background

Earlier chapters have described some of the problems with the scientific study of creativity, in particular the shortcomings of divergent thinking tests (Forthmann et al., 2019; Plucker et al., 2014; Reiter-Palmon et al., 2019; Runco,2008) and issues concerning motivation, time and domain (Abraham, 2018; Dietrich, 2018). The findings of the cross-sectional study in Chapter 2 showed that any use of DT tests needs to be carefully targeted and two suggestions were made for productive approaches. The first was to use these tests to examine change within individuals (as opposed to differences between them); individuals are likely to be at least somewhat consistent in their creative approach and test-retest reliability is reasonably high (e.g., between .50 and .93 for the Torrance tests; Kim, 2006). The second proposal was to use DT tests as a conduit to verbal reports to compare different creative approaches within the same discrete and bounded task (as in e.g., the protocol analysis of the AUT utilised by Gilhooly et al., 2007). Both of these approaches will be exploited here: the training study in this chapter and a qualitative verbal report study in the following one (Chapter 6). Both sets of data will be brought together in the final study chapter (Chapter 7).

What is the evidence that EC can be trained?

As discussed in Chapter 1, there has been great interest over the past two decades in the potential to improve EC through direct or indirect training (Boot et al., 2008; Goldin et al., 2014; Green & Bavelier, 2008; Rueda et al., 2005; Wass et al., 2011). Several regimens have been tested, including training activities as diverse as mindfulness, aerobic exercise, yoga, video game training and martial arts, as well as more direct computer-based approaches (see Cardoso et al., 2018 for a review of interventions in children; also, Blair & Raver, 2014; Diamond & Ling, 2016; Ericsson & Towne, 2010; Jha et al., 2007; Karbach & Unger, 2014; Klingberg, 2010; Melby-Lervåg & Hulme, 2013; Neville et al., 2013; Paananen et al., 2018; Zelazo et al., 2016). Judging the success of such programmes has been complicated by the fact that "there is not an explicit and widely-agreed upon consensus around the best methodological practices" (Green et al., 2019, p. 2), making it hard to evaluate effectiveness rigorously and consistently. Green and colleagues liken the question 'Does cognitive training work?' to the question 'Do drugs work?' i.e., one that is impossible to answer without much greater precision about dosage, delivery, scheduling, recipient population, definition and duration of beneficial effect, existence of side effects and more.

Notwithstanding these difficulties, Diamond and Ling (2016) reviewed 84 recent studies which met certain criteria (presence of comparison groups, publication in a peer-reviewed journal, measurement beyond immediate effects, evidence of benefit beyond improvement on the trained task itself and ruling out studies which were solely correlational). The implied background of the analysis (the title of the paper suggests that some EC programmes have been 'hyped') is that some claims about EC training constituting a kind of holy grail – a practical, bounded intervention with rivers of cascading benefits – have been overblown. Their own conclusions were more modest; whilst the evidence shows that EC can certainly be improved with training, transfer effects (i.e., the extent to which improvements extend beyond the precise task trained on) tend to be narrow. "People improve on the skills they practice and that transfers to other contexts where those same skills are needed" (p.36) but not beyond. Training on working memory, for example, will not improve self-control or flexibility (Melby- Lervåg & Hulme, 2013). Gains also depend on practice – both in quantity (higher dosage being more likely to lead to greater gains) and quality (effective practice requiring steadily increasing difficulty levels which consistently tax EC skills; Ericsson & Towne, 2010) and gains tend to diminish once practice stops (Klingberg et al., 2005). Diamond and Ling also emphasised the importance of seeing EC not as some separable 'bolt-on' set of functions but as a highly connected and particularly vulnerable part of brain function. "Prefrontal cortex and EFs [EC] suffer first and most if you are stressed, sad, lonely, or not in good physical health" (Diamond & Ling, p.41). Training will be most effective if it is scaffolded in programmes which also work to support emotional and social health and well-being.

Training studies have a broad range of goals, from those which seek to understand the mental processes underlying training-induced change to those more concerned with understanding what methods of training are most effective in the real world. Green and colleagues suggest that more clarity and candour about these goals could help specify the most appropriate methods and establish best practice (Green et al., 2019). For example, 'mechanistic studies' are less interested in *whether* cognitive enhancement works and more in *how* it works, an emphasis quite different from an effectiveness study which lets an intervention out into the wild (e.g., a school) and examines whether it achieves its desired impact. These different goals immediately suggest different best practice – for example, while a mechanistic study might prefer an active control group as a way of specifying and testing the 'active ingredient' of an intervention, an effectiveness study might be more interested in a 'business as usual' type control group, which would be better positioned to address the question of whether the intervention constitutes improvement on current practice.

Principles of EC training relevant to the current work

EC is not a single entity and evidence points to a differential involvement of distinct EC components to creativity (Beaty & Silvia, 2014; Benedek et al., 2014a; Vartanian et al., 2020). For example, flexibility might make a positive contribution to creativity through allowing tractable examination of alternative ideational pathways, or through more meta-level flexibility allowing for fluidity of movement between evaluative and associative processes (Nijstad et al., 2010; Zabelina & Robinson, 2010a). Inhibitory control, by contrast, might make a negative contribution through its excessively restraining effect on the potential ideational field such that potential idea candidates are either not considered or are considered and ruled out (Cheng et al., 2016; Radel et al., 2015) - though other studies report beneficial effects of inhibitory control (Beaty & Silvia, 2012; Mayseless et al., 2015a). Evidence from the earlier cross-sectional study (Chapter 2) partially supported previous findings from the literature of a positive role for working memory in verbal DT tests (Benedek et al., 2014a; Zabelina et al., 2019) but also suggests that creativity does not steadily improve with age in the same way that EC does (Barbot et al., 2016; Runco, 2016). The qualitative study (Chapter 3) suggested three relevant pieces of evidence: a key role for flexibility in allowing fluidity of movement between more and less controlled approaches, a potentially detrimental effect of excess control and the finding that children vary a great deal in the level of effortful control they deploy in their creativity. In short, there is evidence, both from the current work to date and the wider literature, which implicates different aspects of EC differentially in creativity rather than clear evidence regarding just one component. This was one reason for seeking a training intervention which trains EC broadly. Another important reason was, given the primary goal of evaluating far transfer to creativity, to maximise the chances of this effect by adopting a broad 'whole child' approach rather than a more limited one focusing on a single narrow skill (e.g., targeting working memory).

This means, per Green et al. (2019), that one goal here is feasibility – most simply, we are testing the viability of this training regime. However, given that we are also interested in the effects on creativity of specific EC components (something we can only do indirectly, through looking at pre and post-tests on those components, and which is thus necessarily more speculative), understanding mechanism is also a goal. It should be acknowledged that this dual-purpose design, does not fully adhere to the best practice advised by Green et al.

The list of whole-class interventions which train multiple aspects of EF, are suitable for a short intervention and have a strong evidence base of proven effectiveness is short. Many programmes which seek to improve EC do not explicitly train it but rather use exercise, mindfulness, action video games as indirect / implicit trainings (Diamond & Ling, 2016; Green & Bavelier, 2008; Karbach & Unger, 2014; Zelazo et al., 2016). Others are so embedded in the whole school approach that they are hard to extricate e.g., Montessori (Lillard & Else-Quest, 2006; Lillard et al., 2017). Some train parents to train their children (e.g., Neville et al., 2013). Many lack specificity so might include EC training but not exclusively EC e.g., 'reasoning training' or 'speed training' (Mackey et al., 2011) or metacognitive and working memory training (Cornoldi,

2015) or 'higher order cognitive strategy training' with effects on EC (e.g., Motes et al., 2014). A contrasting set train only one EC factor. Many of the best-known programmes focus solely on working memory (e.g., CogMed; Shinaver et al., 2014; Shipstead et al., 2012), others on inhibitory control (Zhao et al., 2018) and still others on cognitive flexibility / task switching (e.g., Karbach & Kray, 2009). Some are focused on helping specific children e.g., those with EC deficits (mostly ADHD; e.g., see Spencer-Smith & Klingberg, 2015, for a meta-analysis) or very young children (e.g., Tools of the Mind (Barnett et al., 2008) or the Chicago School Readiness Programme; Watts et al., 2018b), without evidence of effectiveness beyond those groups. Others are too invasive in terms of frequency / duration / parental involvement (e.g., Braingame Brian is 25 x 50-minute sessions; Prins et al., 2013), cost (e.g., SMARTS programme is $599 per teacher) or requirement for expert administration (e.g., Braingame Brian, e.g., Vugs et al., 2017). Other reported programmes have methodological issues such as a lack of active controls, self-selecting groups, or findings which have not been published in peer-reviewed journals (Diamond & Ling, 2016).

Details of the current EC intervention

The programme selected as most appropriate for this study uses a specially designed set of small-group and individual games, each targeted at specific components of EC (Benzing et al., 2019; Röthlisberger et al., 2012). The programme has evidence of effectively improving EC in children as young as 5 and as old as 12. In the first reported study of its use (Röthlisberger et al., 2012), 5- and 6-year-olds were trained in daily sessions of 30 minutes over 6 weeks, a total dosage of 900 minutes. Pre and post-tests, which measured working memory through an object recall task, interference control with a simple Flanker test and flexibility with the mixed Flanker, suggested the intervention had brought about improvements (albeit differentiated by age group and EC factor) of small to medium size of effect (Cohen's d between .42 and .59). A major shortcoming was the use of waiting list controls so, as the authors acknowledge, the Hawthorne effect cannot be ruled as the catalyst for improvements.

The second study (Benzing et al., 2019) involved 10- to 12-year-old children. The dosage was lower than the previous study, involving two 30-minute sessions a week for 6 weeks, i.e., a total dosage of 360 minutes. The control group was again a group of children on a waiting list, who continued with 'business as usual' classroom lessons. Pre and post assessment tested the same triad of EC components as the previous study, using very similar tests. Effects of small to medium size (partial η^2 of .03 and .06 respectively) were found for improvements of the training group in updating (working memory) and shifting components.

This intervention programme met the search criteria in most ways; the main shortcoming of the studies was their use of waiting list controls, something which will be addressed in the current study. Further detail regarding the content and procedures of the training will be detailed in the Methods.

Choice of control

As mentioned, there is currently active debate in educational neuroscience regarding the best kind of control group in randomised controlled trials (Green et al., 2019). In an ideal world, there would be two controls – one 'active', matched as closely as possible on everything except the proposed active ingredient of training and the other 'business as usual', to ascertain whether a training is an improvement on current practice. This is to help distinguish between three main candidate explanatory factors for performance change pre and post-test: namely, practice effects (improvements explained by tests being completed for the second (or third or more) time), developmental effects (improvements explained by non-training specific improvements in other test-relevant factors e.g., faster processing speed, larger vocabulary) and training effects (improvements explained by the intervention itself). The Hawthorne effect (which describes behaviour modification in response to being observed; see Levitt & List, 2011) is also a potential source of performance improvement. A business-as-usual control facilitates assessment of developmental and practice effects, while an active control seeks, using the strictest criteria (i.e., improvements beyond those seen in a group actively engaged with tasks comparable on all dimensions except the specific one of interest), to assess the direct effects of training. Here it was unfortunately not practically possible to include both types of control (none of the primary schools in the recruitment area had three classes per year group; additional separate schools would have meant additional unknown / unmeasurable factors). Since this study is concerned with the mechanisms and processes involved in creativity, a closely matched active control group was chosen. Earlier cross-sectional data (presented in Chapter 2) will provide proxy evidence of developmental effects (i.e., the size of improvements that might be expected over the time course of the study for this age group) while studying children within a narrow age range will also seek to minimise these effects. Practice effects, which will be considered in the light of evidence from the creativity literature (Abraham, 2018; Barbot, 2019, Runco, 2008) must still be considered as a possible explanatory factor of any improvements in performance.

Methods

Aims of study

The study sought to investigate causality in the EC/creativity relationship, progressing from the correlational approach of the studies described in Chapters 2 and 3 to establish more directly whether improvements in EC, brought about by specifically training it, might have far transfer to creativity. In terms of expectation, there are theoretical grounds to believe that an overly controlled approach - one that might be induced by EC training - might have negative creative consequences, primarily through placing excessively tight constraints on the domain for potential ideas. There is some limited laboratory-based research that corroborates this, while studies in more natural environments are rare (Cheng et al., 2016; Limb & Braun, 2008; Radel et al., 2015). Findings from triangulating qualitative and quantitative data here concur with the idea that too much control can have negative effects on fluency and flexibility as well as, though less consistently, on originality. There is also reason to believe that improving cognitive flexibility, generally considered a key EC component, could have positive consequences for creativity, which also benefits from a flexible approach (Nijstad et al., 2010; Zabelina & Robinson, 2010a). Given the intervention targets EC broadly, training might also help children to apply and maintain concentration on the creativity task.

In practice, there are barriers. EC training has been widely shown to be effective in improving the immediate targets of training targets but even local transfer of EC training improvements appear hard to attain while evidence of far transfer is scant (Boot et al., 2008; Diamond & Ling, 2016; Goldin et al., 2014; Green & Bavelier, 2008; Rueda et al., 2005). Since here the goal was to assess far transfer from EC training to creativity performance, expectations of large effects were necessarily modest. However, given the emphasis currently placed on training EC skills in children, it is important to investigate possible side effects of such an approach.

In this randomised controlled trial, half the children were given a programme of training designed to improve EC skills and the other half – the controls - were given a matched programme without the explicit EC component. The first aim of the study was to see whether the training intervention achieved its desired goal of improving EC, measured by testing performance on EC tests before and after the intervention. This led to the second aim of the study, and the primary interest, which was to ascertain, again using change in scores before and after the intervention, whether any aspects of creativity were affected, positively or negatively, by the EC training. More specifically, the study sought to further test the hypothesis that increased levels of control negatively impact creativity.

Ethics

The study was given ethical approval by the Departmental Ethics Committee of Birkbeck's Department of Psychological Sciences, reference number 181989. Safeguarding procedures were carried out in accordance with Birkbeck and Centre for Brain and Cognitive Development policy documents and online advice from Care Quality Commission and the National Society for the Prevention of Cruelty to Children. There was nothing in the previous experience of testing or in the publications regarding the intervention to suggest any negative consequences, most children reporting finding both fun and engaging. If for any reason during testing, children became upset or did not want to continue with a particular test, they were allowed to stop immediately and without question.

Recruitment and participants

State schools, with their mixed ability intake, allow findings to be extrapolated most broadly and all state primary schools in the researcher's local London borough were approached to take part. Schools showing initial interest were prioritised according to those with at least two classes per year group, to allow matching of intervention and controls with children of the same age. After meetings with several head teachers to discuss the intervention and work out feasibility and scheduling issues, two schools were chosen for the study.

Parental / carer consent was sought in conjunction with the schools. Letters were sent to all parents / carers of children in the research classes well in advance of the research starting and open meetings held with parents / carers to discuss any questions and concerns. In addition, all children were given letters before the study commenced to tell them about the research and let them know they could decide whether or not to take part. (Copies of letters are in the Appendix). No participants opted out of the training programme, which was delivered as part of normal lessons, to whole classes. On the days of testing, additional verbal consent was sought from all participating children. On two occasions, a child did not wish to complete one or more of the tests involved.

Participating children were in school years 4 and 5, between 8 and 10 years of age. This age group was selected because children are young enough for EC still to be developing (and still pliant to training) but old enough to be able to write and read instructions independently (a practical consideration) and for suitability of the training programme. Unlike the first study, which covered a wide age range, here the age group was narrow, to reduce the likelihood of significant developmental effects over the four months that the study took place.

A total of 156 children in six classes took part in the intervention, 83 girls and 73 boys. The mean age was 9.27 years, with a range from 8.10 to 10.29 years. Eighteen children had statements of Special Educational Need, 8 in control group classes and 10 in EC training classes. The training, both EC and controls, was designed for whole classes of mixed abilities and all children were included.

Power analysis

A priori power analysis (Cohen, 1992) was carried out using G*Power (Faul et al., 2007) to ascertain the sample size needed for repeated measures 3x2 ANOVA with two between-subject groups and three time points. Effect sizes were conservatively estimated on the basis of previous research using the same training materials (Benzing et al., 2018; Röthlisberger et al., 2012). The analysis indicated that, to detect an effect size of 0.18 (i.e., the lowest of the effect sizes in the previous research, converting Partial η^2 to Cohen's d), with 90% power and an alpha of 0.05, a sample size of 138 would be needed. It should be noted that accurate a priori power analysis is not specified for multilevel mixed models, so an estimate based on repeated measures ANOVA was used as the closest approximation. Nonetheless, the power analysis suggests that the study was appropriately powered to detect the expected effects.

Design

The study examined the effects of an EC training programme on children in years 4 and 5 of two primary schools. Whole classes were randomly assigned within year groups and schools to either intervention or control groups, as shown in Table 5.1

Pre-test assessments were carried out in the two weeks prior to the start of training. Training took place over a 6-week period, in three 30-minute sessions per week, in children's usual classrooms

	Year 4	Year 4	Year 5	Year 5
School 1	EC class (n=27)	Control class (n=25)	EC class (n=22)	Control class (n=24)
School 2			EC class (n=29)	Control class (n=29)

Table 5. 1 Distribution of classes and schools and participants per class, in intervention and control groups

with their regular teachers plus assistance from the research team. The total dosage of training was 540 minutes (9 hours). After the training, all children were re-tested within two weeks of training completion and finally a third time 6-8 weeks later.

Procedure

Fig. 5. 1 Schedule overview

Pre, post, and follow-up tests were all conducted in the same way. Six children were tested at a time; they came out of their class to a nearby room (usually the art room) and were seated at tables arranged so it was hard to see each other's work. All children carried out creativity tests first, using paper and pencils provided, then were tested on computerised tests of EC, tests being administered on either Apple i-pads or Kindle fires. Response measurements on Gorilla (described below) have been shown to be highly consistent across these different platforms (Anwyl-Irvine et al., 2020b). Since the focus of interest was individual change over time, complication of order effects was avoided simply by always administering tests in the same order, namely: creativity tests, Simple Flanker, Complex Flanker, Animal Stroop. The only exception was the working memory test, which some children completed before and some after the other EC tests. WM testing was done individually, in a quiet area outside the main room.

It was not possible for the researchers to be blind to condition during the training. However, all scoring and analysis of EC and creativity tests was carried out blind to condition.

Details of training programme

The training programme centred on small group games, played in groups of 4-6 children. The games involved memorising and applying rules (e.g., if the moon is showing, name the nocturnal animal; if the sun is out, name the diurnal one), switching between rules within a game (e.g., sort insects by number, then by species), inhibiting prepotent motor responses (e.g., slap the card with the red spider but not the black one), keeping and working with information in mind (e.g., remember a list of animals, which are injured and which can fly), maintaining visual attention (e.g., spotting a previously highlighted item which is now missing) and so on. There were five games in total.

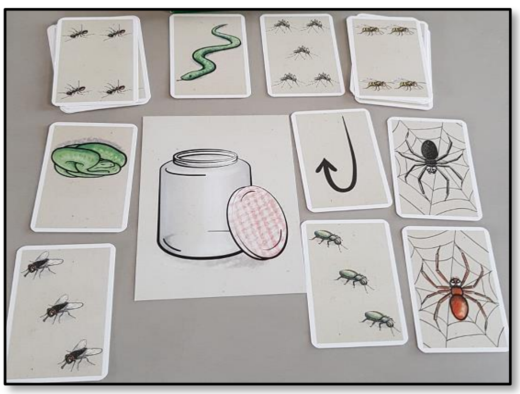


Fig. 5. 2 Examples of EC intervention games 'Insect collection' and 'Day and night'

In the first three weeks of training, new games were introduced each week. By the second half of training, the games were known, but got harder. Each game consisted of multiple levels; once early stages were mastered, new rules and adaptations meant that children's EC was continually taxed with greater levels of difficulty. In addition, children switched groups and player roles frequently, meaning they had constantly to adapt to new adversaries. Children spent half of one of the weekly sessions playing individual games, also designed to train EC and with gradually increasing difficulty levels (e.g., dot-to-dot type puzzles, which required them to find and match dots joining pairs of minutely differentiated shapes, amongst an increasing number of distractor shapes, rather than simply follow a numbered sequence of dots).

A full guide to all the games and activities of EC and control groups is in the Appendix.

For the control classes, the structure, dosage, timing and incrementally increasing difficulty levels were all matched as closely as possible. This was to isolate the hypothesised 'active ingredients' of EC training, i.e., those aspects specifically concerned with training EC such as inhibiting prepotent responses, switching between rule sets, juggling information in working memory and striking a balance between speed and accuracy. In the control group, traditional card and board games were used – children played Snakes and Ladders, Uno, Scrabble, Brainbox and Rummikub.


Fig. 5. 3 Examples of control games 'Snakes and ladders' and 'Scrabble'

Just as with the EC training group, the games were introduced at a simple level, with extra elements and rules gradually added, so that children were constantly having to meet new challenges. Again, as with the training group, one half of one weekly session was given over to individual worksheets (including word searches and crossword puzzles).

It is important to point out that having whole classes of children learning and successfully playing any kind of small group games almost certainly invokes executive control. Games invariably involve turn-taking, waiting, learning, and applying rules, managing emotions and more. It was thus a consideration that the control group was somewhat 'impure' in that it too was likely encouraging children to exercise and practice EC. The design was such that the additional specific EC-targeted elements of the training group would elevate improvement above and beyond this. For example, in one EC game, children learned that a speedy reaction to turning over an 'awake snake' card earned them a bonus, whereas a similar reaction to 'sleeping snake' brought a penalty; the EC games were full of these sorts of requirements, in which components of EC (here, reacting quickly to inhibit a prepotent motor response) were specifically rehearsed.

Teachers in both training and control classes were fully trained in all the games and given a programme instruction manual, detailing when children should move up from one level to the next, the rotation of the games etc. It became clear that administering small group games in mixed ability classes of 30 children required a minimum of two adults, particularly when new games were being taught. In practice, this meant that the researcher (myself and/or a research assistant) were present in all the sessions, to ensure that the training was properly administered. To avoid the confound of having an additional person present for one condition but not the other, the same set up was replicated for control classes.

The games were not designed to measure performance directly; instead, children's performance was indirectly assessed through their successful completion of all levels over the training period. Teachers maintained class completion sheets for each training session, constituting evidence that the training was completed. With the exception of occasional absences due to illness, all children attended all training sessions.

Measures

Executive control measures

The EC measures were mostly the same as those in Chapter 2, where they are fully described. Here, only a brief description and details of any change in protocol will be outlined.

Working memory

Working memory was tested using the backward digit recall test (St Clair-Thompson & Gathercole, 2006), in which children are asked to repeat back, in reverse order, a sequence of digits read aloud by the researcher. The protocol was adjusted slightly from the previous study, to allow tests to be completed in a shorter time; here, three rather than four trials per list level were given and children moved up to the next level if they answered correctly for at least 2 out of 3. This is one fewer trial per list than outlined by Gathercole and Pickering (2000) but one more than has been used in many other studies (e.g., Clark et al., 2004). In all other respects, testing was the same. Since the focus here is on individual change over time, the fact that scores are not directly comparable to the previous study should not be a concern.

Inhibitory control tasks

Animal size Stroop

A child-friendly version (Catale & Meulemans, 2009) of the original Stroop test (Stroop, 1935) was used, as described in Chapter 2. The stimuli, timings, and proportion of congruent to incongruent tests were all as before. The differences were that this time the test was programmed using the Gorilla Experiment Builder (www.gorilla.sc) and children completed the test on Apple i-pads or Kindle fires rather than on desktop computers. Reaction time measurements have been shown to be reliably equivalent across these different platforms (Anwyl-Irvine et al., 2020b). The number of trials was also fewer, again to allow testing within necessarily stricter time constraints. There were 8 practice trials, in which children were given feedback, followed by 24 non-feedback trials. Reaction times and accuracy were recorded.

Simple Flanker

The same child-friendly version of the Flanker task (Eriksen, 1995), adapted from Rueda and colleagues (2004), was programmed and delivered on the Gorilla Experiment Builder (www.gorilla.sc). The differences from previous testing were, as with Animal Stroop, that children used Apple i-pads or Kindle fires rather than desktop computers and the number of trials was reduced. There were 8 practice trials, in which children received feedback on their answers, then 16 trials where they did not (a further 16 followed immediately after with the addition of a new rule, as outlined below). Reaction times and accuracy were recorded.

Switching task

Complex Flanker

The complex Flanker was an additional test added to assess switching flexibility. The version used here was a dimensional sort (Diamond & Kirkham 2005) akin to the 'Dots' (Diamond et al., 2007) or the 'Hearts and flowers' (Diamond & Wright, 2014) task in which different cue colours or shapes point to different rules for how to respond. In this procedure, the task followed directly from the simple Flanker with the introduction of a new rule; if the fish were blue rather than orange, children had to answer for the direction of the surrounding rather than the central fish. If fish were orange, they continued as before. They were still instructed to answer as quickly as possible while trying to get the answer right, but now had to keep two rules in mind and switch between them. Although this task involves working memory (to remember rules) as well as inhibition (to stop to consider which is the appropriate rule) the key measure extracted here was the so-called 'switch cost' – the difference in reaction time between switch and non-switch trials.

Research consistently shows that switch trials, which involve shifting from one rule to another, reliably take longer than non-switch trials, in which the same rule continues (Monsell, 2003). There were 8 practice trials, in which children received feedback on their answers, then 16 trials without feedback, of which half were switch trials. Both reaction times and accuracy were measured.

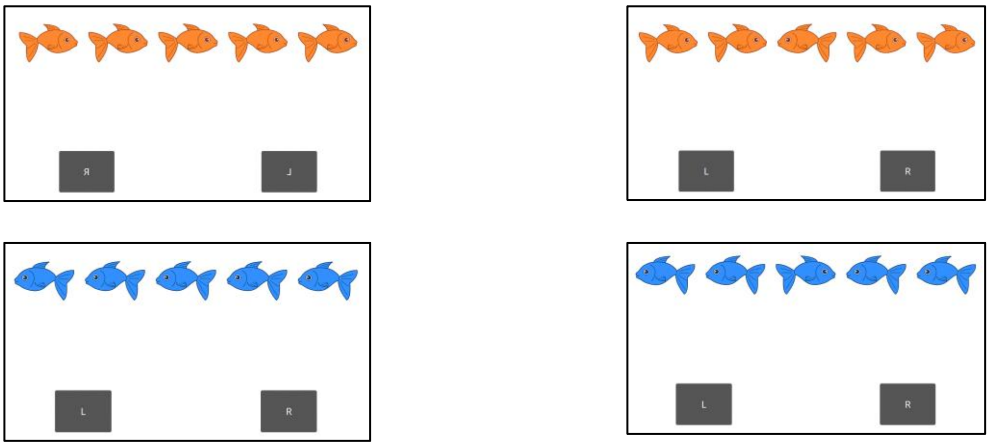


Fig. 5. 4 Complex Flanker: the four permutations of rule type (focus on central or surrounding fish) and congruence (surrounding fish are swimming the same or different direction from the central fish).

Creativity measures

Creativity was measured in two domains, verbal and figural. To help make for as un-test-like an environment as possible (Runco, 2008, 2014; Runco & Acar, 2012), creativity tests were carried out first i.e., to minimise a sense of time pressure and to emphasise levity and fun. Children were encouraged to use their imagination to come up with unusual ideas and it was emphasised that there were no right or wrong answers.

Alternative Uses Test

The AUT (Guilford, 1978) requires participants to generate as many 'interesting and unusual' uses for an everyday object within a time limit. This time, answers were scored for fluency and originality. Additional measures of flexibility and elaboration were not included, since previous work has shown flexibility to be so highly correlated with fluency (Forthmann et al., 2018; Plucker et al., 2014; Rieter-Palmon et al., 2019) and elaboration was deemed a less fundamental aspect of creativity. The objects chosen as targets were (in order): plastic water bottle, pencil, and sock.

As discussed in detail previously, there is vigorous debate about the best way to measure originality. Here, the sample size allowed for use of the frequency method, as outlined by Plucker and colleagues (2014) and deemed to be the most objective method of scoring (Forthmann et al., 2018; Plucker et al., 2014; Runco, 2014). Responses are scored according to their statistical rarity; here, responses scored 2 points if given by fewer than 2% of respondents, and 1 point if given by between 2 and 5%. Responses given by more than 5% of respondents received no points for originality. The overall originality score is, following from Forthmann and colleagues (2020a, 2020b) a ratio score, calculated as the sum of individual response points divided by the number of responses. Fluency was a simple count of responses, discounting any repeats or copies of the prototypical stated use (e.g., for a pencil, 'drawing' or 'writing').

Torrance Tests of Creative Thinking

The TTCT figural tests (Torrance, 1974, 2014) are simple paper and pencil drawing games in which children complete drawings from a range of starting stimuli. A test involving the production of multiple pictures from the same repeated starting point, was used here. Measures of fluency (number of responses) and originality (points for responses not on a pre-determined list of exclusions) were used; these are the core creativity sub-measures and allow comparison across domains. Since the Torrance tests only have two versions, a third was created for follow up, with comparable starting stimuli. Details of this and issues relating to it are considered in the Results. The starting stimuli were (in order): parallel lines, circles, and triangles.

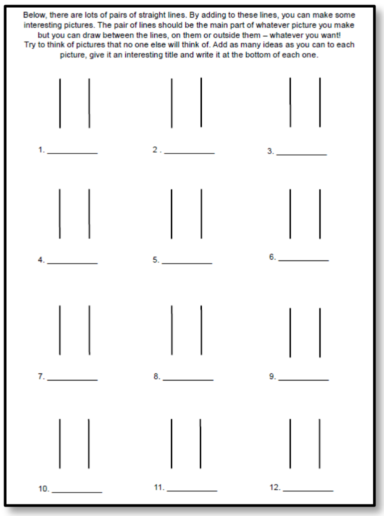


Fig. 5. 5 Example of TTCT figural sheet, with parallel line starting stimuli

Results

A total of 156 children were included in the analysis, 83 girls and 73 boys. The mean age was 9.27 years, with a range from 8.10 to 10.29 years. Eighteen children had statements of Special Educational Need (SEN), 8 in control group classes and 10 in EC training classes.

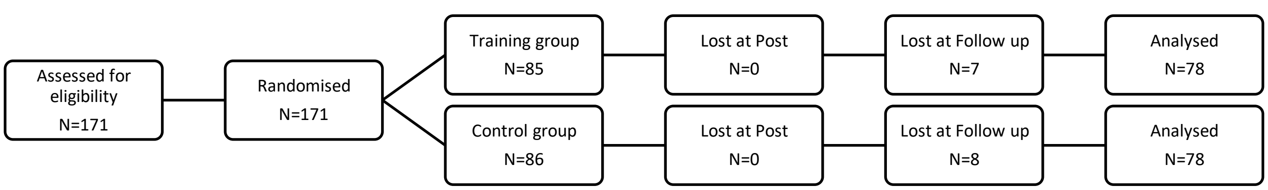


Fig. 5. 6 Consort diagram, showing numbers in intervention and control groups throughout the study duration

The results will be presented in sections, to answer the following questions:

- Did training take place in accordance with instructions?
- Did the test measures work as expected?
- Were there changes in the relationship between EC and creativity over time?
- Were there changes in performance over time and were they differentiated by condition?
- Did additional factors, e.g., age, gender, affect outcomes?

Did training take place in accordance with instructions?

The training involved 3 x 30-minute sessions for 6 weeks i.e., 18 sessions in all. Completion rates were high. All year 5 classes (both EC and control in both schools) completed all 18 sessions. Both year 4 classes (one EC and control) fully completed 17 out of 18 sessions and partially completed the one other session (it ran for 20 minutes instead of 30 minutes in both cases). No children opted out of the training.

Did the test measures work as expected?

In this section, the primary goal is to establish whether the measures used to test EC were reliable, and to critically evaluate the scoring of the creativity tests.

Pre-processing of computerised EC measures

Measurement impurity is 'a ubiquitous problem in cognitive assessment' and not one that can be definitively solved (Willoughby et al., 2018) but efforts can be taken to minimise noise. The noisiness of reaction time data is compounded when RT difference scores are used (comparing mean RTs for congruent and incongruent trials), since they conflate the noise of both measures. Noise reduction is often achieved by increasing trial numbers, but here practical constraints made high trial numbers difficult. Instead, to minimise noise, median reaction times were calculated for each child, in addition to accuracy scores. The table below shows percentage accuracy and median RT means for congruent and incongruent correct trials in Animal Stroop and Simple Flanker for each measurement time point.

			T1		T2		T3	
			Accuracy %	Mean of median RTs (ms)	Accuracy %	Mean of median RTs (ms)	Accuracy %	Mean of median RTs (ms)
Animal Stroop	Cong	Mean	97.8	1057	99.3	1005	98.0	890
		SD	8.6	443	2.9	339	7.2	227
	Incong	Mean	95.5	1191	97.2	1120	97.0	997
		SD	7.9	429	6.5	453	10.1	247
	Diff	Mean	2.3	127	2.1	115	1.0	106
		SD	11.9	260	5.9	268	6.2	147
Simple Flanker	Cong	Mean	87.6	1213	95.9	975	96.4	860
		SD	21.3	741	10.6	390	10.9	307
	Incong	Mean	76.5	1458	90.0	1122	92.0	1021
		SD	32.2	1340	22.8	825	18.6	693
	Diff	Mean	11.1	188	5.9	118	4.4	155
		SD	20.9	213	20.3	647	13.8	509

Table 5. 2 Descriptive data: median RTs and accuracy scores for Stroop and Simple Flanker at all time points (n=156). Cong = congruent condition; Incong = incongruent condition. T1 = pre-test (baseline); T2 = immediate post-test and T3 = follow-up

As expected for this age group, accuracy scores were close to ceiling in both tests, with many children scoring 100% accuracy in both conditions (congruent / incongruent) even at baseline. 51.1% of participants scored 100% accuracy in both conditions in the Flanker and 61.5% in the

Stroop. These high numbers mean that accuracy measures will not be sufficiently sensitive to detect change over time; consequently, only RT measures will be considered in further analyses.

Correlations between EC measures

The first table shows correlations between EC measures at baseline (T1). The expected correlation between the two EC tests theoretically tapping similar inhibitory control processes is not seen. Nor does there appear any correlation between working memory and the other measures, unexpected given the composite nature of EC.

	Stroop RT diff	Simple Flanker RT diff
Working memory	-.04	-.03
	.618	.675
Stroop RT diff		-.08
		.331

Table 5. 3 Pearson's correlations (top) and related probabilities (below) between Flanker and Stroop reaction time (RT) differences at baseline.

The subsequent tables assess test-retest reliability through correlations between RT differences within the same test over time.

	Stroop RT diff T2	Stroop RT diff T3
Stroop RT diff T1	.12	.06
	.151	.483
Stroop RT diff T2		.25**
		.002

Table 5. 4 Correlations between Stroop RT difference over time. Here, and in all subsequent reports,

* represents significance at <.05 level and ** significance at <.01 level.

Again, correlations are much lower than would be expected for a fully reliable measure, with only one combination (Stroop T2 / T3) showing significant correlation. Table 5.4 shows correlations for the Stroop. Table 5.5 shows correlations for the Flanker:

	Simple Flanker RT diff T2	Simple Flanker RT diff T3
Simple Flanker RT diff T1	.09	-.11
	.293	.191
Simple Flanker RT diff T2		-.12
		.133

Table 5. 5 Pearson's correlations between Simple Flanker RT difference over time.

Scatterplots of T2 scores plotted against T1 suggest the reason for this lack of correlation: there is a great deal of clustering of scores around zero.

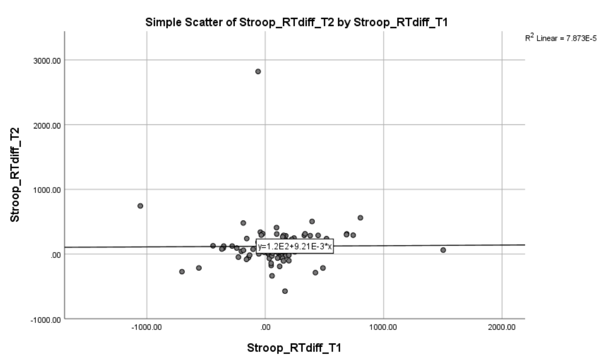


Fig. 5. 7 Scatterplot of RT difference scores in Stroop test plotting T1 baseline against T2 post-test.

Some prominent outliers in these data warranted further investigation. The figure below shows the Cook's distances (a measure of the influence of data points on results in regression analysis) for the sample for the Stroop test. Although Cook's distances suggest strong influence of particular data points, they do not point clearly to where a cut-off for outliers should be. For this reason, and the fact that the study involved a real-world intervention for children of highly varied ability, no outliers were removed.

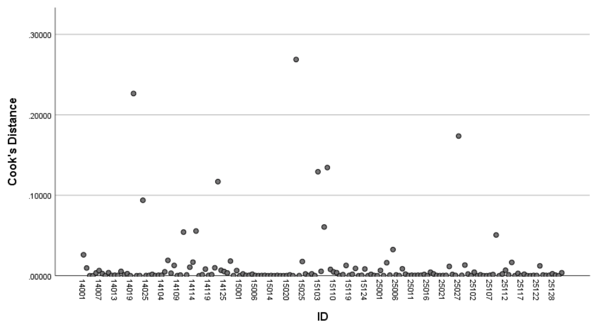


Fig. 5. 8 Cook's distances for regression of RT differences scores of Stroop time 2 on time 1.

These longitudinal data suggest that RT difference is not a sufficiently reliable and valid measure here. Its noisiness means it will be unable to reliably detect training effects i.e., it has insufficient test-retest reliability to pick up change over time, the key indicator needed.

Instead, an alternative measure was evaluated: median reaction time for incongruent trials (correct responses). This measure should theoretically still capture the relevant EC component of inhibiting a prepotent response (i.e., because such control is only required for incongruent trials), but has the confound of incorporating base level individual differences. Since the analysis will consider within-individual change over time, to some extent this confound is controlled for. Bivariate correlations suggest this new RT incongruent measure is more reliable for Stroop:

	Stroop RT incong T2	Stroop RT incong T3
Stroop RTincong T1	.49**	.55**
	<.001	<.001
Stroop RTincong T2		.62**
		<.001

Table 5. 6 Pearson's correlations between RT incong over time for Stroop.

And also for Simple Flanker:

	Simple Flanker RTincong T2	Simple Flanker RTincong T3
Simple Flanker RTincong T1	.44**	.34**
	<.001	<.001
Simple Flanker RTincong T2		.67**
		<.001

Table 5. 7 Pearson's correlations between RT incong over time for Flanker

This also produces significantly correlated scores in the different, though theoretically related, variables of Stroop and Simple Flanker, at all time points. Whilst these cross-measure correlations are reassuring with respect to the robustness of the measures, it should be borne in mind that they might equally reflect baseline respond speed (i.e., as opposed to the more specific underlying EC construct).

	Flanker RT incong T1	Flanker RT incong T2	Flanker RT incong T3
Stroop RT incong T1	.38**	.35**	.36**
	<.001	<.001	<.001
Stroop RT incong T2	.14	.43**	.40**
	.114	<.001	<.001
Stroop RT incong T3	.22**	.41**	.47**
	.009	<.001	<.001

Table 5. 8 Pearson's correlations between RT incongruent trials in Stroop and Flanker at all time points

To ensure that the Stroop / Flanker effect is still present (i.e., despite the problems with RT difference scores), paired samples t-tests were carried out on accuracy scores to compare performance on congruent and incongruent trials. In all cases (i.e., both tests and all time points), the differences in accuracy were highly significant.

		T1	T2	T3
Animal Stroop	t	3.20	4.41	2.41
	df	155	155	155
	sig	.002	<.001	.017
Simple Flanker	t	4.40	3.64	4.03
	df	155	155	155
	sig	<.001	<.001	<.001

Table 5. 9 Paired sample t-tests, comparing accuracy difference between congruent and incongruent trials for Stroop and Flanker at the three test time points

The distributions for RT incongruent scores showed problems of deviation from normality for both Stroop and Flanker so the data were log transformed. This transformation also addressed the fact that RT scores do not follow a linear trajectory to zero, but rather an L shape to the limit of possible reaction speed. Given the high correlation between Stroop and Flanker RT incongruent scores, a combined mean score was created to reduce noise. In all subsequent analyses this single combined measure was thus used to represent the inhibitory control component of EC. These combined scores (both raw and log versions) over time and by condition are shown in Table 5.10 below. The final correlation matrix for the selected EC variables is shown in Table 5.11. Note that the correlation between working memory and inhibitory is negative since better performance is reflected by a higher WM score but a lower inhibitory control score.

		RT incongruent T1 Mean (SD) in ms	RT incongruent T2 Mean (SD) in ms	RT incongruent T3 Mean (SD) in ms
Inhibitory control combined raw score	TOTAL	1327 (746)	1105 (486)	1006 (407)
	EC	1363 (824)	1079 (422)	968 (316)
	Control	1281 (675)	1093 (511)	969 (354)
Inhibitory control combined log score	TOTAL	3.06 (0.16)	3.01 (0.14)	2.97 (0.13)
	EC	3.07 (0.17)	3.00 (0.13)	2.96 (0.12)
	Control	3.05 (0.15)	3.00 (0.13)	2.96 (0.12)

Table 5. 10 Inhibitory control (RT incongruent) raw and log combined scores over time

	Working memory T2	Working memory T3	Inhibitory control log score T1	Inhibitory control log score T2	Inhibitory control log score T3
Working memory T1	.64** <.001	.67** <.001	-.29** <.001	-.41** <.001	-.38** <.001
Working memory T2		.79** <.001	-.35** <.001	-.39** <.001	-.39** <.001
Working memory T3			-.35** <.001)	-.47** <.001	-.44** <.001
Inhibitory control log score T1				.49** <.001	.51** <.001

Inhibitory control log score T2	.79** <.001

Table 5. 11 Pearson's correlation matrix for final working memory and inhibitory control measures used for subsequent analysis

Complex Flanker

No significant difference was found between reaction times for congruent and incongruent trials in this test. There were large individual differences in RT difference scores, with almost half children not showing any switch cost (i.e., incongruent trials did not incur longer RTs than congruent trials). Similarly, accuracy scores failed to show the expected switch cost, with no significant difference in accuracy between trial types; only half the children had higher rates of accuracy on non-switch than switch trials. Alternative measures had insufficient trial numbers or too many children at ceiling to consider. This measure, for reasons which will be elaborated in the discussion, did not work properly here and it was decided not to include it in further analyses.

Working memory

This score is a simple count of correct responses. The distribution of scores was normal with no outliers, so raw scores were entered without further processing into subsequent analyses. Scores for the whole sample, and the different condition groups, are shown in the table below.

	T1	T2	T3
Total	7.07 (2.75)	8.16 (3.11)	8.64 (3.37)
EC	7.14 (2.59)	7.92 (2.73)	8.61 (3.18)
Control	6.87 (2.93)	8.32 (3.57)	8.59 (3.68)

Table 5. 12 Working memory raw scores, means (SDs) by condition, over time

To summarise, two final EC measures will be used for all further analyses: the log score of the combined median RT for incongruent trials and the working memory raw score.

Creativity measures

TTCT figural tests

Scoring of this test was carried out as outlined by Torrance (1974) using the most recent scoring guide (2016) with some adaptations. Firstly, responses were scored only for fluency and originality (the full Torrance scoring also includes elaboration and a points system for creative strengths, applied to the complete test battery). Fluency is a simple count of the number of responses minus excluded responses; responses are excluded if they fail to incorporate the starting stimulus, are only abstract patterns or duplicate previous responses. Originality is measured by summing the number of responses given which are not on a pre-defined list of common responses. The list which determines originality scoring was adapted from the Torrance scoring guidelines for several reasons:

- Despite being the most recent edition, the list is outdated, particularly in the area of technology. Several common responses for modern items are missing from the exclusion list e.g., 'phone' for parallel lines, which was given by more than 5% of respondents
- There are other puzzling omissions e.g., 'pizza' for circles, which was given by more than 10% of the sample, but is missing from the list (whereas 'pie' is included)
- Conversely, some items on the list of common responses were not given by any children in the current sample e.g., 'gift' or 'picture frame' for parallel lines or 'coin' or 'stoplight' for circles

- There is some cultural specificity in that certain responses are likely only to be given by certain populations e.g., the 'Illuminati' sign was given by more than 5% of the current sample because it is currently popular in youth social media memes, but is not on the list
- The Torrance lists have 18 exclusions for parallel lines and 29 for circles with no explanation for this large difference in number
- The Torrance has only two forms, but here there were three test points. A third test, and its exclusion list, had to be created to allow comparison across the three testing sessions – so it was logical to create consistent exclusion lists for all test points.

The new lists were based on the statistical frequency of responses, while maintaining the binary scoring of the Torrance approach. A response given by fewer than 4% of the sample received one point for originality while a response given by more than 4% received zero. 4% was chosen as the cut off to give a quantity of exclusions comparable to the Torrance list. The exclusion list for each test was:

Time 1 (parallel lines)	**Time 2 (circles)**	**Time 3 (triangles)**
House	Face	Star
Tree / trunk	Sun	Diamond
Book	Pizza	Triangle
Bottle	Ball/football	House or roof
Water bottle	Flower	Pyramid
Rocket	Moon	Hat
Door	Cat	Human face or figure
Phone	Clock	Tree / Christmas tree
Rectangle	Person / girl / boy	Pizza
Ladder	Earth	Ice cream / ice cream cone
Pencil	Circle	Rocket
Window	Snowman	Mountain
Face	Plate	Tent
Cup	Dog	Illuminati sign
Box	Orange	Alien
Eye		Cheese

Table 5. 13 List of responses given by >4% of children and receiving no points for originality

It is notable that just as the Torrance scoring method fails to differentiate an extremely common from a somewhat common response (both types appearing on the exclusion lists), it also fails to differentiate a highly original response (e.g., 'Man jumping on a pogo stick over lines') from a slightly original one (e.g., 'Church'). The per-child score is calculated as a simple sum of all the originality points. The nature of this scoring method means that, while it is possible to have high fluency coupled with high or low originality, it is very difficult to achieve high originality coupled with low fluency. A child who produces only a few responses of a highly original nature is not highly rewarded - in contrast to AUT scoring. All scores showed normal distributions and the finite number of starting stimuli constrained possible outliers.

		T1 (pre)	T2 (post)	T3 (follow up)
Fluency	Total	3.83 (2.09)	4.63 (2.84)	4.94 (2.57)
	EC	3.60 (2.15)	4.53 (2.79)	5.03 (2.68)
	Control	4.01 (2.02)	4.71 (2.93)	4.83 (2.47)
Originality	Total	2.74 (1.69)	2.36 (1.99)	2.73 (2.07)
	EC	2.60 (1.68)	2.49 (2.10)	2.87 (2.07)
	Control	2.83 (1.67)	2.23 (1.91)	2.58 (2.07)

Table 5. 14 Scores for TTCT figural tests at the three time points, whole sample and by condition. Means and standard deviations (brackets) are shown.

Alternative Uses Test

This test was also scored for fluency and originality. Fluency was calculated as a simple sum of responses, minus any exclusions. Exclusions were of three types: a repeat of the stated prototypical use (e.g., 'drink water out of it' for water bottle), an overly generic response (e.g., 'do something with it') and repeats (e.g., 'wash your hands with it' followed by 'use it to wash your hands'). Exclusions are not made by judgment even if it is unclear how the object might be used in that way (e.g., a water bottle as 'a jumper').

The issues raised by originality scoring have been discussed previously (see Chapters 1 and 2; also, Forthmann et al., 2020b). There is continued, vigorous debate about how best to score it (Forthmann et al., 2020a, 2020b; Plucker et al., 2014; Runco & Jaeger, 2012; Said-Metwaly et al., 2017; Simonton, 2018) often linked to different theoretical positions about the process by which creativity is achieved. Issues such as sample size also affect scoring decisions – for example, frequency-based measures can be unreliable for small samples (Reiter-Palmon et al., 2019; Silvia et al., 2008). Here, originality was assessed by the objective measure of statistical rarity of responses (Cropley, 1967; Mayseless, 2015a; Runco, 2008), with the application of a scoring formula to each response as follows:

>5% respondents give the answer	0 points
2-5% respondents give the answer	1 point
<2% respondents give the answer	2 points

Scores are then summed for that participant and divided by their fluency score – to produce an overall originality score per child. In contrast to the TTCT, this scoring method makes it harder to achieve high originality with high fluency than with low fluency (though low originality can be achieved with both high and low fluency). Some would argue this is the most accurate reflection of real-world creativity: in a short space of time, it is difficult to produce a large number of high-quality ideas (Silvia et al., 2008; Torrance, 1966). An advantage of having two different emphases in originality scoring across the two tests is that it increases the credibility of any finding common to both.

		T1 (pre)	T2 (post)	T3 (follow up)
Fluency	Total	3.40 (2.41)	4.26 (2.91)	5.08 (3.02)
	EC	2.99 (2.02)	4.31 (3.27)	5.31 (3.52)
	Control	3.78 (2.69)	4.18 (2.53)	4.86 (2.43)
Originality	Total	0.92 (0.58)	0.90 (0.56)	0.70 (0.51)
	EC	0.88 (0.63)	0.94 (0.57)	0.79 (0.58)
	Control	0.95 (0.52)	0.86 (0.55)	0.61 (0.43)

Table 5. 15 Fluency and originality in AUT at three time points, full sample and by condition. Means and (standard deviations).

Some examples of particularly original responses for each stimulus are shown below (original spelling is retained):

Plastic bottle	Pencil	Sock
A snorkel	You could use it as equipment for an Egyptian when they are taking things out of people's nostrils and ears	If you are a burglar to black out cameras
Seperating eggs	Using a giant one as a polvolt stick	A poo bag for dogs
Keep your arm warm with fabric on it	It could be a bug seesaw	Reindeer antler warmers
Amagen it is a person to talk to	You could make nests for birds	Make it smell of something and use it as a memory
A balloon pump	It can be used as a cabab stick	A wind sock
Make a fake toilet role	A nose for Pinochio	Bookmark
Belly flopping on a pool of them	You can stick the pointy bit into an orange so it's easyer to eat	Putting on top of shoes to skate (sort of)

Table 5. 16 Verbatim responses scoring highly for originality for each stimulus object.

There was a high level of correlation between sub measures both within each domain and also between verbal and figural domains. This cross-domain correlation is by no means always the case with creativity measures which often appear domain specific (Baer, 2010).

	TTCT originality	AUT fluency	AUT originality
TTCT fluency	.79** <.001	.41** <.001	.22** <.001
TTCT originality		.41** <.001	.25** <.001
AUT fluency			.45** <.001

Table 5. 17 Pearson’s correlations and related significance values between creativity measures at baseline

Having established the details of the EC and creativity measures, we can now move on to look at change over time.

Was there change in the relationship between EC and creativity over time?

Before coming on to the effect of condition on change over time, we report here an analysis considering change in the correlations between EC and creativity measures over time. This analysis will become more relevant when we come on to discuss the main findings regarding the effects of training. The following considers all participants, collapsing EC and control groups. At baseline (T1), there was no strong relationship between EC and creativity variables, with only working memory showing a small significant correlation with originality in the verbal domain.

		Inhibitory control	TTCT fluency	TTCT originality	AUT fluency	AUT originality
Working memory	r	-.29**	.12	.07	.11	.18*
	CI (95%)	[-.43, -.14]	[-.04, .27]	[-.09, .22]	[-.04, .27]	[.02, .33]
	p	<.001	.147	.423	.157	.026

Inhibitory control	r	.01	-.02	.05	-.09
	CI (95%)	[-.15, .17]	[-.18, .14]	[-.11, .21]	[-.25, .07]
	p	.900	.796	.559	.267

Table 5. 18 Pearson's correlations between EC and creativity measures at baseline (T1).

By T2 and T3 (post-test and follow up) most correlations between EC and creativity measures became stronger and highly significant. The following tables show results using Pearson's correlation coefficients, but the more conservative Spearman's correlation coefficient produced very similar results.

		Inhibitory control	TTCT fluency	TTCT originality	AUT fluency	AUT originality
Working memory	r	-.39**	.29**	.17*	.22**	.11
	CI (95%)	[-.51, -.24]	[.14, .43]	[.01, .32]	[.06, .36]	[-.05, .26]
	P	<.001	<.001	.036	.006	.169
Inhibitory control	R		-.20*	.01	-.28**	-.25**
	CI (95%)		[-.35, -.04]	[-.15, .17]	[-.42, -.13]	[-.40, -.10]
	P		.013	.926	<.001	.002

Table 5. 19 Pearson's correlations between EC and creativity measures at post-test (T2).

The final table (5.20) shows results for T3:

		Inhibitory control	TTCT fluency	TTCT originality	AUT fluency	AUT originality
Working memory	r	-.44**	.37**	.29**	.36**	.11
	CI (95%)	[-.56, -.31]	[.23, .50]	[.14, .43]	[.22, .49]	[-.05, .26]
	P	<.001	<.001	<.001	<.001	.176
Inhibitory control	R		-.22**	-.23**	-.26**	-.03
	CI (95%)		[-.37, -.07]	[-.38, -.08]	[-.40, -.11]	[-.19, .13]
	P		.006	.004	.001	.702

Table 5. 20 Pearson's correlations between EC and creativity measures at follow-up (T3).

The general trend is an increase in correlations over time, most clearly seen with the correlations between working memory and fluency, which increase steadily over the three time points, in both figural and verbal domains. The correlation of TTCT originality with both EC measures also increases, though less consistently (the increase is seen between T2 and T3 but not T1 and T2). AUT originality differs; it is the only measure with lower correlations with both EC measures at the end of testing than the start. This is shown graphically below in Fig. 5.9.

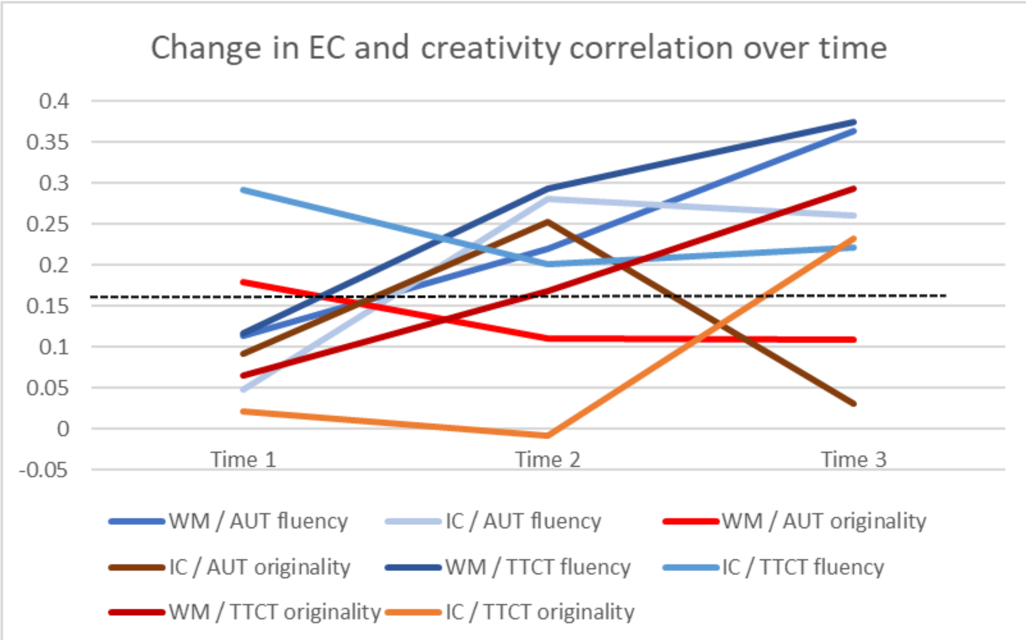


Fig. 5. 9 Change in correlations between EC and creativity variables over time. Blue spectrum colour lines show correlations with fluency measures, red spectrum with originality measures. For ease of reading, polarity of inhibitory control correlations has been reversed. The black dotted line shows the critical significance level for p=.05, for the sample size of 156 at r=.16

Were there changes in performance over time and were they differentiated by condition?

This section analyses whether there were significant changes in how children performed in the EC and creativity tests over time, and whether this differs between the EC intervention group and controls. Each outcome variable was analysed with a linear multilevel mixed model, to account for the nested nature of the data – both within individuals and between them, since different classes and schools were involved. In each case, to account for correlated random effects, participant and class were specified as random factors with random intercepts, and the correlated residuals within the repeated measures were accounted for using an autoregressive covariance structure (i.e., the assumption that adjacent time points are likely to be the most highly correlated). This covariance structure was chosen on the basis of theory and after checking that it improved model fit, as measured by a lower AIC (Akaike information criterion).

Experimental condition (EC or control), time (baseline, post and follow up) and the condition*time interaction were specified as fixed factors. Age was not included as a covariate here but was represented by the inclusion of class in the model. School was not included since there were only two schools (insufficient for random effect modelling) and since school variance was accounted for by including class in the model. Results are reported first for EC variables and then for creativity variables. Standardised betas are not typically produced in this kind of analysis but for ease of interpretation and for the benefit of those unaccustomed to LMM reporting, they have been calculated (by running the analyses with the variables z-scored) and are shown here - estimates are shown in italics. Note that the other, non-italicised values in each table refer to the unstandardised scores. Best practice suggests that the most accurate main effects are produced by models which exclude interaction terms; however, in practice those results were almost indistinguishable from those which included the interaction term, and in the following tables, the main effects of time reported are from the full analysis. Time and condition are dummy coded relative to baseline for time and to the control group – so the intercept refers to control group scores at baseline (T1). Change over time is also represented graphically for all measures, in Fig. 10, following the LMM reports.

EC variables

Working memory

The resulting model showed a significant effect of time $F(2, 203.73) = 36.32$, $p < .001$ but no significant difference between conditions $F(1, 6.21) = 0.01$, $p = .920$ and no significant interaction between condition and time $F(2, 203.73) = 1.17$, $p = .311$.

	Stand. effect size	Effect size estimate	Standard error	T	Sig	Confidence intervals	
						Lower	Upper
Intercept	-*.32*	6.88	0.58	11.91	<.001	5.52	8.23
Condition	*.06*	0.18	0.82	0.22	.831	-1.74	2.10
Time-post	*.44*	1.38	0.30	4.67	<.001	0.80	1.97
Time-follow up	*.53*	1.67	0.26	6.37	<.001	1.15	2.18
Interaction-post	-*.19*	-0.62	0.42	-1.47	.144	-1.44	0.21
Interaction-follow up	-*.06*	-0.17	0.37	-0.47	.639	-0.91	0.56

Table 5. 21 LMM estimates of effect sizes for change in working memory scores

There was significant variation both within and between participants. The different sources of the observed variation is indicated in the table below.

	Estimate	Standard error	Wald Z	Significance
Within participant	3.72	0.72	5.15	<.001
Between participants	4.93	1.05	4.70	<.001
Between classes	0.67	0.53	1.27	.205

Table 5. 22 Estimates of covariance parameters for WM

Inhibitory control

The model showed a significant effect of time $F(2, 207.18) = 46.89$, $p < .001$ but no significant difference between conditions $F(1, 6.20) = 0.06$, $p = .816$ and no significant interaction between condition and time $F(2, 207.18) = 0.21$, $p = .809$. Estimates of effect sizes are shown in the table.

	Stand. effect size	Effect size estimate	Standard error	t	sig	Confidence intervals	
						Lower	Upper
Intercept	*.31*	3.06	0.02	123.13	<.001	3.00	3.12
Condition	*.12*	0.02	0.04	0.47	.653	-0.06	0.10
Time-post	-*.30*	-0.05	0.02	-2.78	.006	-0.08	-0.01
Time-follow up	-*.59*	-0.09	0.01	-6.32	<.001	-0.12	-0.06
Interaction-post	-*.12*	-0.01	0.02	-0.58	.560	-0.06	0.03
Interaction-follow up	-*.09*	-0.01	0.02	-0.58	.561	-0.05	0.03

Table 5. 23 LMM estimates of effect sizes for change in inhibitory control scores

There was significant variation both within and between participants.

	Estimate	Standard error	Wald Z	Significance
Within participant	0.01	0.00	4.64	<.001
Between participants	0.01	0.00	2.65	.008
Between classes	0.00	0.00	1.16	.248

Table 5. 24 Estimates of covariance parameters for inhibitory control

Creativity measures

TTCT fluency

There was a main effect of time $F(2, 224.09) = 16.66$, $p < .001$. There was no main effect of condition $(1, 5.86) = 0.13$, $p = .730$ and no interaction between condition and time $F(2, 224.09) = 1.17$, $p = .311$.

	Stand. effect size	Effect size estimate	Standard error	t	sig	Confidence intervals	
						Lower	Upper
Intercept	-*.18*	4.01	0.35	11.37	<.001	3.22	4.80
Condition	-*.16*	-0.42	0.50	-0.83	.426	-1.53	0.70
Time-post	*.28*	0.71	0.31	2.30	.023	0.10	1.31
Time-follow up	*.33*	0.83	0.28	3.03	.003	0.29	1.38
Interaction-post	*.08*	0.19	0.43	0.44	.658	-0.66	1.05
Interaction-follow up	*.22*	0.57	0.39	1.47	.144	-0.20	1.34

Table 5. 25 LMM estimates of effect sizes for change in TTCT fluency scores

	Estimate	Standard error	Wald Z	Significance
Within participant	3.88	0.62	6.25	<.001
Between participants	2.23	0.69	3.22	.001
Between classes	0.14	0.17	0.81	.420

Table 5. 26 Estimates of covariance parameters for TTCT fluency

TTCT originality

There was a main effect of time $F(2, 221.95) = 4.11$, $p = .018$. There was no interaction between condition and time $F(2, 221.95) = 1.37$, $p = .257$, nor a main effect of condition $F(1, 5.98) = 0.06$, $p = .820$. Note that the effect of time here did not represent straightforward improvement (as it has with other performance changes so far presented), but rather a decline between T1 and T2, followed by recovery between T2 and T3.

	Stand. effect size	Effect size estimate	Standard error	t	sig	Confidence intervals	
						Lower	Upper
Intercept	*.11*	2.59	0.33	7.82	<.001	1.84	3.35
Condition	-*.11*	0.22	0.47	0.47	.651	-0.85	1.29
Time-post	-*.32*	-0.14	0.22	-0.64	.525	-0.58	0.30
Time-follow up	-*.13*	0.23	0.25	0.94	.348	-0.26	0.72
Interaction-post	*.25*	-0.47	0.31	-1.52	.131	-1.10	0.14
Interaction-follow up	*.25*	-0.49	-.35	-1.40	.165	-1.18	0.20

Table 5. 27 LMM estimates of effect sizes for change in TTCT originality scores

	Estimate	Standard error	Wald Z	Significance
Within participant	2.54	0.42	6.10	<.001
Between participants	0.90	0.43	2.10	.036
Between classes	0.20	0.16	1.23	.219

Table 5. 28 Estimates of covariance parameters for TTCT originality

AUT fluency

The model showed a significant effect of time $F(2, 236.15) = 28.95$, $p < .001$ as well as a significant interaction between condition and time $F(2, 236.15) = 4.05$, $p = .019$. Both groups improved their scores over time, but the EC group improved more, starting with lower scores than controls at baseline but producing higher scores by follow up. Overall, the main effect of condition was not significant $F(1, 6.19) = 0.01$, $p = .926$.

	Stand. effect size	Effect size estimate	Standard error	t	sig	Confidence intervals	
						Lower	Upper
Intercept	-*.17*	3.77	0.36	10.36	<.001	2.97	4.57
Condition	-*.27*	-0.76	0.51	-1.48	.167	-1.89	0.37
Time-post	*.14*	0.40	0.33	1.22	.225	-0.25	1.04
Time-follow up	*.38*	1.08	0.31	3.43	.001	0.46	1.70
Interaction-post	*.32*	0.92	0.46	2.00	.047	0.01	1.84
Interaction-follow up	*.43*	1.23	0.45	2.77	.006	0.36	2.11

Table 5. 29 LMM estimates of effect sizes for change in AUT fluency

	Estimate	Standard error	Wald Z	Significance
Within participant	4.18	0.55	7.65	<.001
Between participants	3.37	0.73	4.65	<.001
Between classes	0.11	0.17	0.63	.530

Table 5. 30 Estimates of covariance parameters for AUT fluency

AUT originality

The model showed there was a main effect of time F(2, 255.69) = 9.46, p < .001. Note that here the change over time was a reduction in scores. There was no main effect of condition F(2, 255.69) = 1.20, p = .313. While the overall interaction between condition and time was not significant, F(2, 255.69) = 2.22, p = .111, there was a significant interaction between T1 (baseline) and T3 (follow-up), as shown in the Table 5.31 below.

	Stand. effect size	Effect size estimate	Standard error	t	sig	Confidence intervals	
						Lower	Upper
Intercept	*.19*	0.95	0.67	14.23	<.001	0.81	1.08
Condition	*-.10*	-.06	0.09	-0.61	.546	-0.25	0.14
Time-post	*-.16*	-0.09	0.08	-1.08	.279	-0.26	0.07
Time-follow up	*-.61*	-0.34	0.08	-4.22	<.001	-0.50	-0.18
Interaction at post	*.27*	0.15	0.12	1.25	.215	-0.09	0.38
Interaction at follow up	*.43*	-0.24	0.12	2.10	.037	0.02	0.47

Table 5. 31 LMM estimates of effect sizes for change in AUT originality scores

	Estimate	Standard error	Wald Z	Significance
Within participant	0.28	0.03	8.99	<.001
Between participants	0.02	0.03	0.68	.494
Between classes	0.00	0.00	0.51	.612

Table 5. 32 Estimates of covariance parameters for AUT originality

To summarise these results, for all variables there was a main effect of time. In the case of WM, IC and both fluency measures, change in time represented better performance. In AUT originality, performance declined over time and in TTCT originality, it declined from T1 to T2, then improved from T2 to T3. There was no interaction with condition for the EC measures, nor for either TTCT measure. There were interactions with condition seen with both AUT measures. For AUT fluency, while both groups showed improvement over time, the EC group showed significantly greater improvement between all time points; for AUT originality, while the

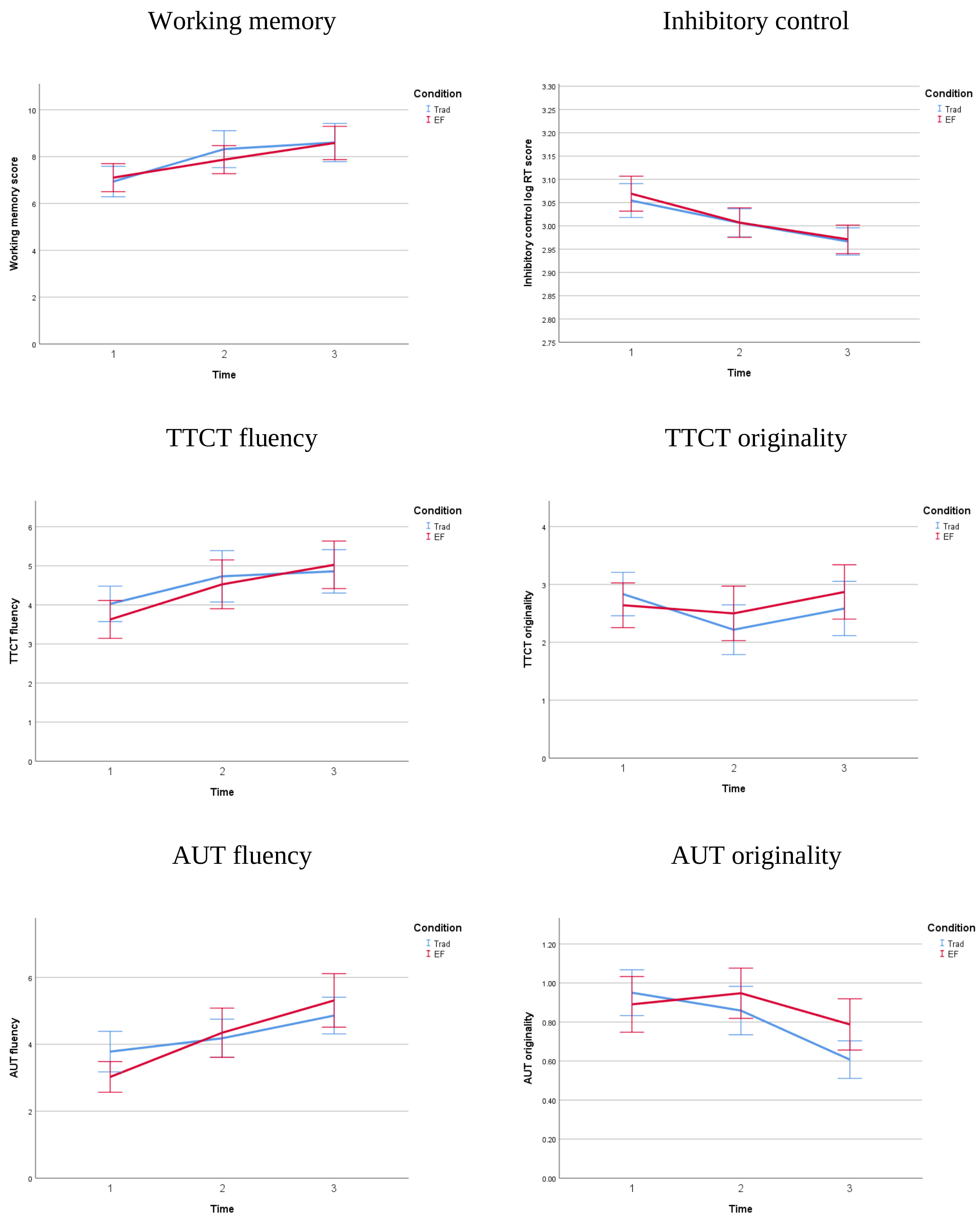


Fig. 5. 10 Change in EC and creativity variables over time, by condition. Error bars show 95% confidence intervals. Red lines show the EC training group, blue lines the control group.

interaction with condition was not significant for the overall model, there was a significant interaction at follow up, the decline in performance being significantly greater for the control than the EC group.

Did additional factors e.g., age, gender, SEN status, significantly affect outcomes?

The general approach in examining additional factors was to aim to reduce the chance of false discovery by only including extra covariates in models if there was a firm theoretical justification for doing so. Evidence from the existing literature suggests that gender is unlikely to be an important covariate (Baer & Kaufman, 2011; Runco & Yoruk, 2014) and no significant effect of gender was found here. Children with SEN, as would be expected, tended to perform at a lower level than children without SEN but their trajectories of improvement over time were very similar i.e., there were differences in intercepts rather than slopes. The figure below for working memory is typical:

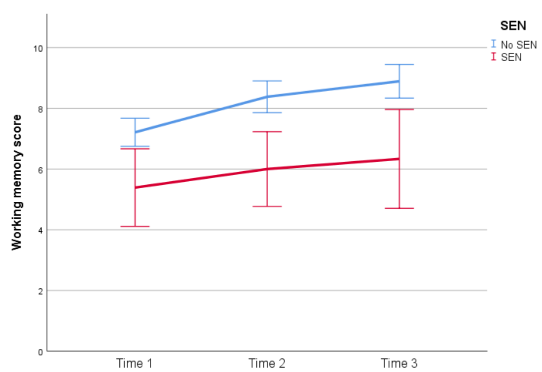


Fig. 5. 11 Change over time in working memory scores, by SEN status

Given the small numbers involved and the even distribution of children with SEN in training and control groups, this covariate was not included in further models.

The factor of age presents the greatest challenge for analysis since there are two conflated factors to account for – the random effect of class and the fixed effect of age. The uneven distribution of classes and year groups within schools (i.e., the fact that School 1 had 4 classes: 2 year 4s and 2 year 5s, while School 2 had only 2 year 5 classes) made separation of these factors more complicated (i.e., because age was not covered evenly) as the graphs which follow illustrate. Again, taking working memory scores as an example, the first graph shows scores at the three measurement time points, separated by year group (as a proxy for age). For cognitive performance measures, we would generally expect better performance in older children, and this was the picture seen here. While scores are lower in younger children, the trajectories of change over time appear similar for both age groups.

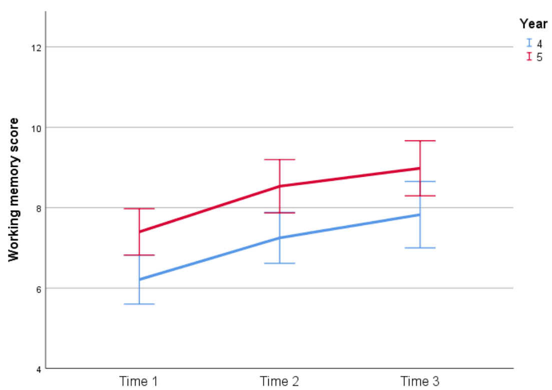


Fig. 5. 12 Change over time in working memory scores, by year group as a proxy for age. Error bars show 95% confidence intervals

The next graph, again showing WM scores over time, breaks down results by class.

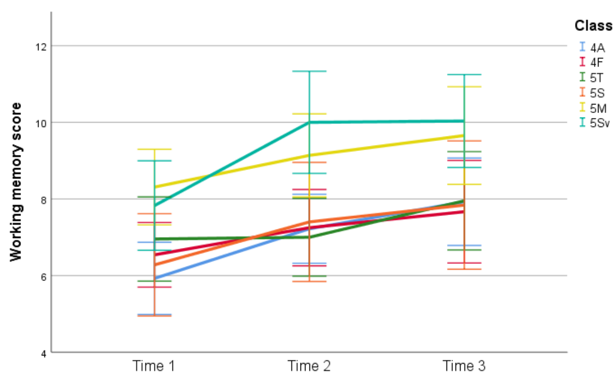


Fig. 5. 13 WM scores over time by class. Error bars show 95% confidence intervals.

It shows that year 5 children at School 2 (the school in which only year 5s participated, classes 5M and 5Sv, represented by yellow and mint green lines) outperform year 4 children at School 1 at all time points, including base levels. But within School 1, there is no clear difference in performance, despite the age differences, between year 4 and year 5 children, even at baseline. In both cases, the trajectories of change appear broadly similar for all classes.

Representing this in a statistical model is not straightforward. Including both age and class (and the relevant interactions) overfits models and causes failure to converge, whilst including either one alone means it absorbs the variance on behalf of both factors e.g., including age in place of class in the model means age apparently explains variance which in reality stems in part from differences between classes. Given that i. the main interest is the effect of different conditions, ii. that there is no theoretical reason to believe that different age groups would respond differently either to the intervention or control group training and iii. that inspection of graphs showing all relevant variables broken down by age gave no reason to suspect age significantly affected outcomes, age was not considered further. The complications caused by the uneven coverage of age within schools will be discussed in the next section.

Discussion

This study set out to examine, through a randomised controlled trial in six classes of two primary schools, whether EC training affected outcomes in measures of creativity. Both intervention and control groups were actively involved in playing small group games over the course of several weeks; the difference was that the intervention group's games were specifically designed to tax EC. Results showed that both groups improved performance in EC measures (verbal working memory and inhibitory control) and in creative fluency in two domains (verbal and figural) over the course of the study. By contrast, creative originality did not improve; in the figural domain there was no overall change in originality and in the verbal domain, it declined. If both interventions (i.e., EC and active control) improved EC, these data would be consistent with the view that creative originality was negatively impacted by EC training.

The discussion will explore possible explanations for these findings which are surprising for several reasons: first, that changes were almost completely consistent across training and control groups (in AUT fluency the training group show significantly greater improvement than controls and in AUT originality, the training group showed less decline by follow up than controls); second, that there appear to be some 'far transfer' effects on creativity, and third, that this transfer was differentiated such that there was a positive effect on fluency and a negative one on originality. The discussion which follows will mirror the sectional structure of the results, before broadening into more general discussion, linking findings to previous studies and the wider literature, and relating findings to the model of creativity being developed across this thesis.

Did the measures work as expected?

Some of the issues which arose with the measures were a result of the trade-off between ideal lab practice and the practical constraints of a real-world study. The example of trial numbers in EC tests is a good illustration of this – the lab ideal suggests a large number of trials to minimise noise but the practical necessity of testing a large number of children in a short space of time makes this difficult: teachers do not want children out of class for longer than necessary and children completing a large test battery inevitably tire. In the case of inhibitory control, RTs of incongruent trials served as an acceptable substitute for the traditional RT difference scores. But in the case of the switching test, it is likely that the small number of trials was largely responsible for this measure failing to work. Given the proposed importance in the model of a broader level 'flexibility' (broader in suggesting movement between thinking approaches rather than between task sets), it is disappointing not to have a measure which reflects flexibility in its narrower EC definition. By contrast with computerised tests, WM was straightforward to test and evaluate, as were the creativity tests.

Explaining change in performance over time

Performance on the intervention was not measured directly (i.e., children were not tested on how well they did in the games, only on the fact that they completed the training) but instead, a 'near transfer' effect of training to other EC tests, as well as a 'far transfer' to creativity were measured. For EC, results showed that both working memory and inhibitory control improved with time. The overall effect sizes of improvements, in an analysis that combined groups, were .19 for WM and .24 for inhibitory control, both very much in line with previous studies (Benzing et al., 2019; Röthlisberger et al., 2012). Fluency in both domains also improved with time, though the effect sizes were smaller (.10 for TTCT and .15 for AUT), as would be expected given the further transfer. Originality in the AUT declined significantly whilst in the TTCT, it was static overall.

We will shortly consider the findings in which differences were seen between experimental groups. But first, we will consider the findings of improved performance in both conditions symmetrically as was seen for most measures. There are various possible explanations for such findings, including one or more of:

- Practice effects. These suggest that children do better on tests second / third time around due to "undesirable influences on test scores relative to the repeated exposure to the test" (Barbot, 2019b, p. 204).

Some practitioners are pessimistic about such effects: "Practice effects on cognitive tests are not a minor nuisance but a major potential problem," according to Wesnes and Pincock (2002, p.473) since their contribution to outcomes is hard to decipher. These researchers argue that even if an intervention group improves more than controls, practice effects cannot be ruled out, because it might be that the intervention facilitated practice effects. This gloomy view is not shared by everyone. In a recent study (Kavanaugh et al., 2019), practice effects were calculated for a large number of participants (roughly 1000 in total, varying by test) involved in computerised cognitive training programmes. Practice effects (results for tests completed approximately 1 month apart, prior to intervention) were calculated for very similar measures as used in the current study. Repeated measures ANOVA found no significant differences for a list-sort working memory recall task and a small but significant difference in Flanker incongruent RT, with an estimated effect size of partial η^2 of .009, a considerably lower effect size than observed here. This evidence suggests that practice effects are unlikely to fully explain the effects seen for EC tests here.

The issue with creativity tests is somewhat different. A unique feature of creativity research is its requirement for originality - meaning that novel tests must be used at each time of testing. Practice effects thus differ in important ways here compared to EC tests, since practice is not on exactly the same test (in fact, when exactly the same tests are used, DT scores have been shown to *decrease* on second testing (McCrae, 1987) a finding attributed to the functional fixedness induced by prior exposure). Whilst in some ways, this is helpful in reducing the likely impact of practice effects (though not eliminating them, since similar strategies and procedures might still be deployed; Barbot et al., 2016) the use of 'alternate forms' ushers in a new problem, that of 'stimulus dependency' (Barbot et al., 2019b). This refers to the fact that there might be differences in difficulty of alternate forms of tasks (Forthmann et al., 2016) or simply that some participants might be more inspired by, for example, a pencil than a sock.

- Familiarity effects. This is a more speculative suggestion, arising from observations during testing.

Familiarity effects (my term rather than a commonly used one) overlap with practice effects in referring to issues arising from repeat testing, but operate at a broader, 'whole participant' rather than purely cognitive level; effects refer to factors such as increased comfort in the setting, familiarity with the researchers, lower anxiety and less stress. In other words, these describe effects caused by improvements to an environment in which relevant cognitive skills flourish, something that might be of particular relevance to EC (Diamond & Ling, 2016; Zelazo et al., 2010). To my knowledge, there are no specific data on such effects.

- Developmental effects. These suggest that children do better on tests as they get older because the cognitive processes involved in completing the tests have become more developed, more diverse, or faster.

Approximately 8 weeks separated pre and post-tests, and another 6 weeks post and follow-up tests, meaning children were roughly 4 months older at the end than the start. The 'slumpy, bumpy' (Barbot et al., 2016) nature of creative development makes reliable estimates of expected developmental change over such a period hard to generate. Evidence from the earlier cross-sectional study (Chapter 2) showed improvement in AUT originality with age, whereas most creativity measures did not significantly improve, even over the much wider age range considered there. Numbers in that study were, as discussed, rather small. A recent large-scale meta-analysis considering more than 40,000 participants from 41 studies, found an overall slow upward developmental trend of DT across grade levels (Said-Metwaly et al., 2020) while a small longitudinal study (Claxton et al., 2005) which tested 25 children at three time points (grade 4, grade 6 and grade 9) did not find significant change in total divergent thinking scores over that time period. In individual sub factors, fluency showed no change, though there was a decline in originality between grades 4 and 6. This finding is in line with the 'fourth grade slump', first proposed by Torrance (1968), which suggests there is a decline in creativity around the age of 9 associated with children entering a 'conventional stage' (Runco, 2014). Many dispute that such a consistent slump really exists (Barbot et al., 2016; Said-Metwaly et al., 2020), and it would in any case be pushed to explain both the size of effect here and the differential effect on fluency and originality. Kim (2011) using a large data set from the Torrance figural test norming samples, found that fluency was static over the age group considered here, while originality showed small increases from fourth to fifth grade (equivalent to years 5 and 6 in the UK). On balance, it seems unlikely that the size and direction of effects seen here could be explained by development alone.

- Training effects. A final set of possible causes of improvements over time were that the training brought about the changes. Any explanation based on training effects must account for the fact that improvements were almost completely undifferentiated by condition.

Unpacking a possible training effect

In most cases, the results seen for the training and control groups were alike, i.e., there was a main effect of time in bringing about improvements but no interaction with condition. The originality decline (AUT) and decline followed by recovery (TTCT) was also symmetrical across conditions. The only interactions with condition were with the AUT. For AUT fluency, both groups improved at each time point but the EC training group improved significantly more. For

AUT originality there was no overall interaction with condition but the follow up declines in performance were less for the EC group. In other words, children largely saw the same gains (or losses in the case of originality) whether they were trained on a specially designed set of EC games or whether they played household games such as Scrabble, Uno and Rummikub. Before we come on to consider the contrasting outcomes for originality, what might explain the improvements common across training and control conditions?

- The training was such that both EC and control groups were effectively being trained in EC skills and this effect transferred to performance on EC and creativity tests. This would suggest adaptability in the details of EC training procedures likely to be effective.
- The training was such that EC was being trained in the EC group and something else (e.g., general processing speed) was being trained in the control group, which had the knock-on effect of improving test outcomes in much the same way
- Both intervention and control groups benefitted from non-cognitive aspects of training – e.g., having fun, playing with friends, doing something joyful and unusual – and these social / emotional factors led indirectly to improvements
- Any combination of the above

Regarding the suggestion that both groups were effectively receiving EC training, it was noted earlier that playing almost any kind of small group games is likely to call upon EC skills – learning and applying rules, taking turns, waiting, resisting jumping in to respond for others, managing the disappointment of losing, staying focused on the game – and more. In the wider literature, there is some tentative evidence that playing board games can benefit cognitive function (Noda et al., 2019), as well as slow down cognitive decline in elderly populations (Dartigues et al., 2013). There is also some evidence of positive associations between board game playing and EC-relevant constructs such as self-efficacy (Gauthier et al., 2018). To complicate matters, there is also evidence that playful, games-based approaches in education can improve creativity (Cremin et al., 2006; Davies et al., 2013); this would lend support to the idea that creative outcomes might have come about not via EC improvements but thanks to transfer of a playful mindset (Howard-Jones et al., 2002). However, the fact that it was only fluency and not originality that improved and that EC improved at the same time make this convoluted explanation unlikely.

In this study, the decision to include an active control group meant there were many, deliberate similarities between intervention and control groups. Both groups played the same number of games in small groups, rotated games regularly, endured increasing levels of difficulty, regularly changed playmates, had to learn, master, and improve on the same number of games and were mostly learning new games. Scheduling of training – dosage, frequency, timing - were also matched across groups. It is a real possibility that the efforts to isolate the 'active ingredient' unique to EC training were too stringent – in other words, the room for differential improvement in the intervention group alone was too narrow. Unfortunately, the attendant lack of a 'business as usual' control makes it extremely difficult to test this theory. It should be noted that, despite the fact that improvement in both conditions was contrary to expectation and complicates explanation, there is potentially a silver lining for those interested in improving children's EC. Namely, the current evidence points to an affordable, easily available, fun means by which to achieve that goal – simply by having whole classes play board games for three short sessions a week. As we shall shortly discuss, however, this might come with a cost to creativity.

Mechanistically, the proposal would be that EC training (across both groups) improved children's ability to stay on task, ignore distractions, simultaneously work with multiple ideas, and attend selectively to appropriate information; these improvements were transferred quite directly to tests of WM and inhibitory control which tapped similar processes. They also led more broadly to improvements in fluency, again through improvements in the ability to juggle more ideas, inhibit previous or exemplar-repeat ideas and apply more strategic search for ideas (e.g., think about what worked before) i.e., the training improved the effectiveness or speed of the reiterative cycle of idea search / retrieval / inhibition (Finke, 1996; Ward et al., 1997). Perhaps the specific EC training (i.e., the EC group not the control group) was particularly effective at these broader level improvements to control and planning, which is why this was the one place where this group saw significantly greater gains. The finding that better EC led to improvements in fluency is contrary to expectation; the prediction from the triangulation study was that greater control would tend to produce generally adverse creative outcomes (i.e., decreases in scores for all sub measures: fluency, flexibility, and originality). Perhaps that view was an over-simplification and greater EC might instead affect the *nature* of the creative process i.e., shifting from the search for ideas being open and far-reaching to being strategic and narrow. Or there might be two factors at play: EC training might allow children to stay on task longer (resulting in greater fluency) but attenuate the generation of high-risk, unusual ideas (resulting in reduced originality).

More evidence suggesting better EC was the basis of fluency improvements comes from the change in correlations between EC and creativity over time. Correlations of both working memory and inhibitory control with fluency in both domains significantly increased from pre to post to follow up, suggesting greater yoking of these processes as time went on. This same increased correlation was not seen with originality. Any valid explanation for the cause of changes post intervention must account for the fact that while most outcome measures saw gains, originality did not. In terms of creativity, the changes were quite specific: after training, children had more, worse ideas. And whether or not it was the training that improved EC, the subsequent test results showed that improvements in EC co-occurred with a deterioration in creative originality. Why might this be?

Dissecting originality

To restate: the results showed improvements in both measures of creative fluency but decline in AUT originality and a lack of overall change in TTCT originality (a significant decline post training was offset by subsequent recovery at follow up). Can this finding for originality be explained simply by its relationship with fluency i.e., is it a side effect of the interdependence of fluency and originality in both tests? These measures are linked in that originality is not possible without at least some fluency (one must first have an idea for it be original) and much has been written about the cross-contamination of sub scores in divergent thinking tests (Acar & Runco, 2019; Barbot et al., 2019a; Forthmann et al., 2016, 2020a; Plucker et al., 2014; Reiter-Palmon et al., 2019; Runco, 1991, 2008, 2014). There are several reasons to question this as the explanation here.

In the AUT, originality is inversely related to fluency (originality points are divided by the fluency score, so other things being equal, greater fluency would reduce originality) whereas in the TTCT, originality is positively related to fluency (i.e., greater fluency would, other things being equal, lead to greater originality) – so if the finding were purely a side effect of fluency, it would be expected to result in opposing outcomes in each test. Further evidence from fluency / originality correlations at different time points also suggests this is not the key explanation. In the AUT, fluency and originality show significant correlations at all time points, but the strength of the correlation declines from $r = .45$ at baseline, to $r = .24$ post intervention and $r = .18$ by follow up. In the TTCT, there is barely any change in the level of correlation over time between fluency and originality scores ($r = .79$ at baseline, to $r = .78$ post intervention and $r = .79$ at follow up).

What else could explain this finding? As previously mentioned, creativity is unusual in repeat test scenarios; given the requirement to 'produce something original with value' (i.e., the definition of creativity; Runco & Jaeger, 2012, the exact same test cannot be repeated. Instead, tests have different forms – i.e., while the test remains the same, the stimuli change, for example from a pencil to a sock for the AUT. Could it have been the case that the starting stimuli were more challenging in later tests – or the first ones were (by chance) the most likely to spark original ideas? Such an explanation would have to align with the finding that more ideas are produced in both cases, since it is only originality which has declined, not fluency.

A related notion is that repeat testing might lead to better fluency but not better originality for reasons other than the decreasing appeal of stimuli. Imagine an instruction: "Work as efficiently as possible, without too much 'thinking outside the box'". Followed strictly, this would produce more, less original ideas. Previous studies bear this out; the counterpart to the 'be creative' effect (the robust finding that the instruction to be creative results in fewer, more original answers) (Forthmann et al., 2016; Nusbaum et al., 2014) is the 'be fluent' effect which improves quantity at the expense of quality (Forthmann et al., 2016; Runco & Acar, 2010). This was, emphatically, *not* the instruction given here, which was 'Come up with as many interesting and unusual ideas as you can', i.e., an instruction suggesting both quantity and quality. However, there are situational reasons why, despite these instructions, the children might have inferred that quantity was the more important attribute:

- The seating arrangements were such that children could see each other's work but were not close enough to read words or see pictures clearly. From afar, the only measure of competitive success was thus the quantity of work others had produced, not its quality.
- The papers they were given contained many empty lines (for AUT) and many empty shapes (for TTCT). This conceivably cued children that volume mattered most.
- Relatedly, quantity is simply easier for children to judge than quality; they can be sure of the number of ideas they have produced, but it is harder to be confident about whether those ideas are any good.
- More subtly, might the idea of working efficiently within clearly prescribed limits chime the most with children's school experience in other subject areas? This is the basis of much schoolwork, from spelling tests to maths lessons to writing stories which must include prescribed grammatical components.

Another possibility is that children are censoring themselves; they are thinking of unusual ideas but ruling them out before writing them down. This could broadly be seen as increased inhibition (Duckworth et al., 2013; Munakata et al., 2011). This might happen if they have been primed to doubt the validity of an answer, something that could conceivably emerge as a result of playing games with penalties for incorrect responses. This inhibitory priming might be stronger as a result of the public nature of the games i.e., the broadcast censure of mistakes. It is possible that this would affect originality specifically rather than fluency as well, since particularly nonconformist ideas might invoke a stronger need for inhibition. A complicating factor for this explanation is that the correlation between fluency and originality in the TTCT is constant.

Or could inhibitory control perhaps have worked at a less conscious and deliberate level to block imaginative responses? Evidence from previous chapters has suggested that being stuck at extremes could lead to creative failure; more specifically, the model predicts that failure at an extreme of control would lead principally to a failure of originality. It is possible that children already vulnerable to a position of too much control (too closed, too blocked) in their creative approach were pushed to this creative cul-de-sac.

A final possible explanation is that wide individual differences are producing the result, less because all children are tending to a similar direction, and more because individuals are responding very differently to training – and the adverse effects on those negatively affected outweigh the positive effects for those who benefit. This relates to the idea in previous chapters that there are many means by which creativity can be achieved. This can be seen by looking at the covariance parameters and the percentage of variation coming from different sources, which are summarised in Table 5.33 (note that totals do not add up to 100 since the random variation due to class is not included).

	WM	Inhib control	TTCT fluency	TTCT originality	AUT fluency	AUT originality
Within	40%	60%	62%	70%	55%	93%
Between	53%	35%	36%	25%	44%	6%

Table 5. 33 Summary of variance within (top) and between (bottom) children on each variable

The graphs below (Fig. 5.14) illustrate the point visually. While changes in EC measures over time are fairly consistent between individuals, originality scores appear chaotic.

Does this point to something unreliable about this measure? Or would it be more accurate to say that what is being measured is itself 'unreliable' – that is to say, inherently fragile, mercurial, even ephemeral? As Simonton says, chronicling the habits of eminent creatives, "at any given time, the performance outcome for a particular work…will be contingent on a chaotic mixture of influences, some beneficial, some deleterious… the creator must somehow generate the right

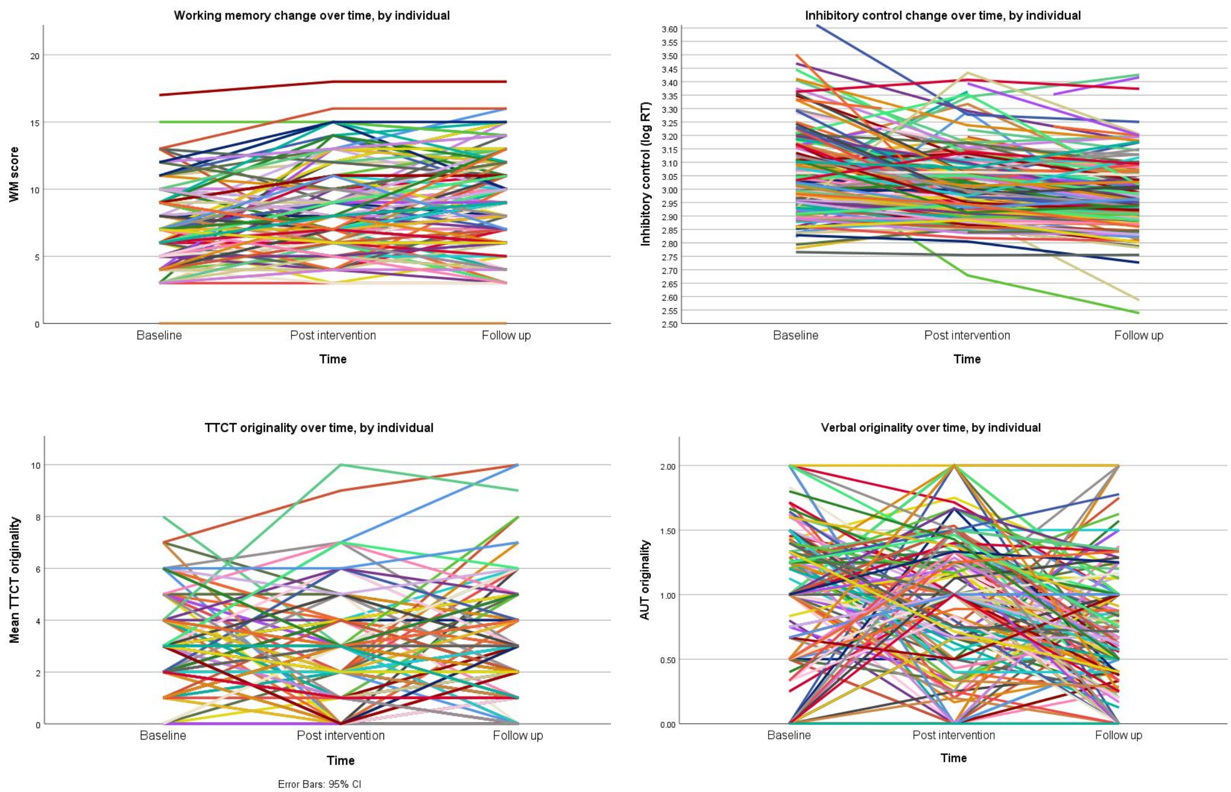


Fig. 5. 14 Graphs showing individual differences in change over time for WM, IC, TTCT originality and AUT originality. Each coloured line represents one child.

product at the right place and at the right time” (Simonton, 2000, p.313). Guilford (1950) himself noted that “creative people differ considerably in performance from time to time,” (quoted in Barbot, 2019, p.209). This points to a suggestion that there are many, small, unmeasured yet influential factors, differing by person, which contribute to someone’s creativity, particularly to their ability to be original. And while it is not a totally surprising finding that originality is unstable – after all, we do not expect to conjure brilliant ideas at will - what is surprising is that it seems particularly vulnerable to improved EC. So, the positive suggestion that this study might point to, a potentially affordable, achievable means of training EC, must be tempered by the evidence that such an intervention might effectively train children away from original thinking.

Limitations

The first, most obvious limitation was the absence of a 'business as usual' control. This made it very hard to distinguish between the training having no effect (the effects being caused by practice / development) and the training having an effect that was the same across conditions. This represents a stark difference of interpretation between 'Nothing worked' and 'Everything worked'. However, given the change seen in both EC and creativity measures across the time period, and previous evidence suggesting this is unlikely to be due to developmental change, the balance of probability is that the effects seen were due to change brought about by shared elements of both training conditions.

The limitation of RT measures has also been discussed. Although the relatively small number of trials in EC tests was a known compromise – in the sense of it being a response to practical considerations – it was a great shame that we had no measure of flexibility here. The problem of the small number of trials might have been exacerbated by the fact this was the final test in the battery; children being tired, bored, or otherwise off-task, might have contributed to the fact this measure did not work. There were similar trade-offs between lab-ideal and real-world testing in creativity tests; while every effort was made to create an 'un-test-like' environment, children are observant; they are aware that there are time limits, that their peers might be producing more answers, that, 'fun' notwithstanding, they are being required to produce ideas on demand. Even if it is possible at the first testing session to maintain an element of surprise, it is very difficult thereafter.

Conclusions and next steps

This study further explored the EC / creativity relationship, moving beyond correlation to study causation, by assessing the effect of EC training on creativity in a randomised, controlled trial. Outcomes were very similar in both the EC training and active control group; the most likely explanation for this is that the control children's EC was also being trained, by playing traditional games. The findings suggest that the training brought about improvements in EC (working memory and inhibitory control) and in creative fluency, but also that it caused deterioration in creative originality. After the intervention, children had more, worse ideas.

In the next two chapters, we will investigate these findings further, using different tools. The first step will be to document the processes involved when children complete divergent thinking tests. As in the previous qualitative study, stimulated recall (this time using AUT responses as cues) will form the basis for structured interviews which will be analysed thematically. Again, the positive and negative contribution of EC processes to creativity will be considered with the aim of establishing more specifically how, when and what type of control processes are detrimental or beneficial. Since the children in this qualitative study were all also part of the intervention, quantitative and qualitative data from the same participants completing the same tests will then have been gathered - and the job of the subsequent chapter will be to bring all these data together. The goal will be to make predictions of possible differentiation of the effects of EC training on creativity across children, dependent on their individual creative approach. This will be the opportunity to interrogate some of our evolving hypotheses e.g., regarding detrimental effects of excessive control, or protective effects of flexibility on creativity. These differential predictions will then be directly tested against the quantitative results of the intervention, with the aim of better understanding how and why particular children's creative performance changed when their EC improved.

Chapter 6. A thematic analysis of children's cognitive processes while completing the AUT

What are the positive and negative contributions of EC to their creative process?

Introduction

In this study, we return to qualitative methodology, this time to analyse the creative process of a divergent thinking task in the school setting. The broad rationale for using qualitative tools and mixed methods to understand the creative process was outlined in chapters 3 and 4 respectively, where the validity of using children's verbal reports as data was also discussed. Here then, we will focus on the new and specific aims and objectives of the current research.

The purpose of this study is twofold. The first is as a standalone piece of qualitative research, exploring and analysing the mechanisms involved in the process of children's completion of the AUT, the most commonly used test of divergent thinking (Forthmann et al., 2018; Runco, 2014) which is often used as a proxy for creativity (Runco, 2008). A better understanding of the processes lying behind the test's completion will help to address some of the gaps in understanding which arise when quantitative data scores alone are used (Gilhooly et al., 2007).

The second purpose stems from the study's being nested within the large quantitative intervention study described in chapter 5. This facilitates relating findings from the qualitative analysis meaningfully and directly to outcomes in the EC intervention study; in turn, this leads to the possibility of drawing firmer conclusions as to whether EC improvements affect creative outcomes differently depending on a child's creative approach. In addition to these broad goals, the qualitative findings may help to shed light on some of the unanswered questions raised by the results of the intervention, in particular the fragility of originality and the mechanisms by which improving EC might have fluency-specific benefits.

Experience from the previous qualitative work, as well as evidence from the wider literature (Meier & Vogt, 2015; Morgan et al., 2007; Vandevelde et al., 2015; Whitebread et al., 2009, 2010) suggest that children are able to articulate and describe their mental processes. This is likely to be particularly true of EC processes, which are often deliberately considered and so more accessible to verbal description (Bryce & Whitebread, 2012; Whitebread et al., 2009, 2010). Clearly children are unlikely to evoke EC in the lexicon of psychology. A failure of selective attention might be articulated by a statement such as 'I could hear clattering next door and it made my mind go blank'; exercising flexibility by 'I'd already done one like a hairclip so I thought I should try and do something different'; a glitch in working memory by 'Did I already do that one?'. The fact that some translation of meaning will be needed carries the risk of misinterpretation, an issue familiar to qualitative researchers (Swartz & Rohleder, 2017; Willig & Rogers, 2017). Tools and strategies to minimise these risks will be outlined in the sections that follow.

Two techniques for verbal protocol analysis were again piloted to find the best tool for the research: these were simultaneous think aloud (Fleck & Weisberg, 2004; Gilhooly et al., 2007; Ward & Traweek, 1993) and immediate post-test stimulated recall (Bloom, 1953; Calderhead, 1981; Lodge et al., 2000; Morgan et al., 2007). Both were evaluated using AUT prompts as stimuli. A primary concern in this study was to achieve consistency across qualitative and quantitative work; specifically, the goal was to maximise the likelihood that the processes involved in the completion of the test in its quantitative and qualitative strands were similar and consistent. This way, in later triangulation, the characterisation of the EC-basis of children's approaches, founded on their qualitative responses, could be compared with their quantitative outcomes pre and post intervention. It was therefore important that the verbal reporting did not, for example, slow down the rate of producing responses or lead to thoughts that would not have arisen without vocalisation. Largely for this reason, simultaneous think aloud was again ruled out here; not only did verbalisation make it hard for children to stay on track (for example, one child, distracted by stumbling over a word, segued into a monologue about tongue twisters), but there was also a reduction in the fluency of responses caused by the extra burden of having to simultaneously report thoughts. Stimulated recall did not suffer such problems and was, as before, selected as the best tool for the current work, with several steps taken to maximise validity (Meier & Vogt, 2015; Morgan et al., 2007), including the following:

- The interview took place immediately. To minimise burden on memory, there was no time lag between the creation of the stimuli responses and their use to evoke recall
- The stimuli themselves were tangible, specific, and newly generated by subjects themselves
- The duration of time over which recall was required was short - 3 minutes, and focused - the children were highly consciously engaged in the activity. This is very different from stimulated recall studies in which participants are asked to give retrospective reports of more distant and unfocused activities, such as their thoughts on a journey to work earlier in the day (Smirnov, 1973), which have reduced validity due, amongst other things, to problems of memory retrieval (Ericsson & Simon, 1984)
- Expertise of questioning. As Petitmengin suggests (2006, 2011), the nature of questioning is key to eliciting accurate responses which focus on individual specifics not norms-based generalities
- As before, the '7Cs' checklist (Cooperation, Coherence, Confidence, Consistency, Confirmation, Contradiction, Corroboration), fully described in chapter 3, was used during the process of transcription and early analysis in efforts to improve rigour

Although 'think aloud' was not considered appropriate here, some of the ideas from Gilhooly and team's (2007) think aloud analysis of the AUT in adults were used, specifically the categorisation of idea responses according to their provenance.

The creative task being used as the basis for analysis – the AUT – differed in many ways from the task in the earlier qualitative study in chapter 3. Firstly, it involved completion not of a free-ranging piece of creative work but of a much more constrained divergent thinking test - limited by time, by materials, by rules and by more specific goals. The timing and environment also changed from an evening or weekend at home to a classroom during normal school hours. As well as potentially affecting the level of EC involvement in the process (higher constraints tending to increase the need for executive involvement; Beaty et al., 2017), these changes are also likely to have wider effects on motivation, engagement, and the emotional response to the task (Agnoli et al., 2018; Collins & Amabile, 1999). The final crucial difference was that the task under examination was the same for all children. This allowed a more detailed and systematic examination of similarities and differences in approach, and crucially (in the next chapter) comparison of scores and approaches for triangulation.

The structure of this study is conceptually somewhat complex. Not only is the qualitative study already nested in a larger quantitative intervention study, but within the qualitative study itself several analytical tools were used to tackle specific research questions. The first part, addressed in this chapter, is the simplest: it is the thematic analysis which aims to describe and analyse the processes involved in the execution of the AUT. It includes an analysis of the nature and level of EC involvement in the entire creative process, i.e., both the productive parts (those which led directly to the production of a response) and the non-productive parts (for example, how a child approached occasions when they felt stuck and no responses were forthcoming).

The second part, addressed in the next chapter, comprised several components which sought to translate the same data more directly into EC-relevant components and to quantify them. The components included, first, an analysis of the directly productive aspects of the creative process, categorising given responses according to their provenance (e.g., memory, the immediate environment, 'popping up'). Second, it involved quantifying key qualitative responses (such as the extent to which there was mind wandering, different levels of concentration, reference to self-edited ideas etc.). Finally, it involved a purely quantitative component: directly scoring AUT responses. These three elements combined to characterise children into creative sub types, for the purpose of generating predictions about how they might have differentially responded to the EC training. The methods and research questions described below form the basis of all these elements, although their analysis is divided between this and the subsequent chapter.

Research questions

A number of research questions, building on work in previous chapters, inform the current work. Some of these can only be partially addressed in this study, with fuller answers dependent also on bringing qualitative and quantitative findings together in chapter 7.

- Is there further evidence of individual variation in approaches to creativity, including state and trait differences in the extent to which control processes, spontaneous processes and flexibility are deployed to creative ends?
- Is there evidence that a high level of inhibitory control is detrimental to creativity?
- Is there evidence that a high level of flexibility is beneficial to creativity?
- Is there evidence which helps explain the apparent fragility of originality?
- Is there evidence of creative failure (in quantity or quality) at either extreme (too much, too little) of control?

Methods

Participants

A sample of 16 children, 8 from an EC and 8 from a control class, representing just over 10% of the full intervention sample, were randomly selected from their class, after exclusion for children with a statement of SEN. All children were in year 5 of the same school. Only year 5s were chosen for a more homogeneous sample and for the likelihood of their being better able to generate verbal reports of retrospective thought processes. Children, carers, and teachers were all given information about the purpose and methods of the study. Following this, consent was sought firstly from teachers, then, in writing, from all parents/carers and finally through verbal consent from each child before the interview. Approaches to data storage and protection were all as described in chapter 3. As before, children chose their own pseudonym, an alternative name to be used in any writing about the research and only these pseudonyms ('Rabbit', 'Squish', 'Pickle my bunions' etc.) are used here. The research received ethical approval from the Departmental Ethics Committee, Department of Psychological Sciences, Birkbeck College University of London, approval number 161762.

Procedure

All interviews were conducted in the same room (a large cloakroom adjacent to the children's classrooms) over the same week. Children were first asked to complete the Alternative Uses Task, this time with 'paperclip' as the stimulus object. They were given 3 minutes (as in the quantitative study), to complete the test on pencil and paper. Immediately afterwards, they were interviewed using stimulated recall, using their written responses as the stimuli to prompt recall.

Interviews consisted of two types of questions: direct questions about the provenance of ideas produced in the AUT and broader EC-relevant questions about their approach to the task, strategies for getting unstuck, level of concentration and so on. At the end of the interview, children were asked to mark any ideas which they had seen or experienced before and to choose their best idea. Interviews were recorded on a small handheld voice recorder (Sony ICD-PX470) and typically lasted around 25 minutes. Very similar questions were put to all children, with some small variation arising from following up specific individual responses:

Interview questions

- What were your first thoughts when I told you what you were going to do?
- (Then, using the answers on the AUT as a stimulus and prompt)
    - Where did this first idea come from?
    - What did you do to the idea in your head before writing it down?
    - Where did this next idea come from? (questions repeated for each idea)
- What happened in your head in between writing down ideas?
- Was there anything you thought of but didn't write down? How did you decide whether to write an answer down?
- Were you ever stuck? Can you describe that feeling? What did you do to get unstuck?
- How would you describe your concentration when you were thinking of ideas? How did your concentration here compare with how it is normally in class?
- Did your mind wander? Where did it go? How did it come back?
- How did you try to think about ideas other people wouldn't think of?
- How did you try and think of lots of ideas?
- If you'd had more time, would you have had more ideas?
- How can you tell what is a good or a bad idea?

- Was there anything different about doing this this time compared to before? Can you describe the difference?

Transcription and analysis process

In line with the interviews, the analysis involved two connected but separate processes – the first was a thematic analysis based on the entire interview transcript and the second incorporated quantifiable elements such as the number of evocations of a particular provenance of responses. The aim was to produce findings at two levels – one to stand alone as a thematic analysis and the second to produce findings which could triangulate, and test predictions made about performance in the quantitative intervention study. The thematic analysis, and related idiographic thematic narratives will comprise the major part of this chapter. The AUT provenance analysis and categorisation of children into 'creative typologies' will be outlined in chapter 7.

Thematic analysis

The underlying assumption of the analysis is that children's descriptions of their mental processes can help reveal underlying mechanisms and processes. The overall aim was to understand the ingredients of the creative process completing the AUT. The analysis focused on the research question 'How do executive control processes contribute, positively or negatively to children's creativity?' across the whole task, including unproductive as well as directly productive elements. The emphasis was not solely on idea generation, but also included processes involved in an idea being refined or reshaped, or times when no ideas were forthcoming. There are two reasons for this: the first is that not enough is known about the creative process to exclude aspects which are not directly productive (e.g., it might be that being stuck is the catalyst for broader search which subsequently produces more original ideas). The second is that the other aspects of the analysis (in chapter 7) will focus on the directly productive aspects.

The aim was to stay close to questions pertaining to EC involvement. This meant not including some interesting but not directly relevant themes (e.g., the social dimension of the creative process or the use of visual imagery). Borderline areas (e.g., themes around stress or time pressure or how children define creativity) were retained, since they spoke to the validity of the data as a reflection of the creative process and gave additional information about how children understood and undertook the task.

The analysis involved similar stages to those described in detail in the first qualitative analysis. As before, the process involved both induction and deduction; children's accounts give rise to new themes and the researcher brings their own theoretical position (Morgan, 2014). Through a shuttling between these processes, the relevant components are gradually conceptualised (Eatough et al., 2008).

After listening to interviews several times and producing transcripts by hand for each child, each transcript was approached, one child at a time, with a focus on the research question. The transcript was considered line by line, assigning descriptions to particular pieces of script (usually at the level of whole sentences, but sometimes phrases). As the process continued, themes and patterns developed, first at the level of the individual, then in later stages of the analysis at the level of the group. For this study, because all children had completed the same creative activity and been asked very similar questions, the move from the individual to group level was more straightforward than before (when children were working in different domains and on different time scales). The final stages again involved an iterative process, moving between themes, descriptions, and superordinate themes, gradually refining, and renaming.

The main thematic analysis findings will be supplemented, as before, with a selection of idiographic thematic narratives for five of the children, selected to illustrate contrasting approaches. The different aspects of the analysis are really facets of the same underlying process (Mason, 2011) and they intersect in various ways, not necessarily linearly. For example, the idiographic thematic narratives can be read as richer individual accounts of the thematic analysis or as the qualitative counterpart to the quantitative characterisation of creative sub types. For the sake of clarity, these aspects will be presented in sections as follows:

In this chapter:

- Thematic analysis. The main findings, subthemes, and superordinate themes of the thematic analysis
- Case studies. Idiographic thematic narratives for a selection of children

In the following chapter:

- AUT performance. Scores for originality, fluency, and flexibility
- Where did ideas come from? Analysis of the provenance of given responses
- Characterising children according to levels of control, spontaneity, and flexibility
- Using these characterisations to make predictions about how children might have been affected by the EC training intervention and testing these predictions against the data.

Findings and analysis

Thematic analysis

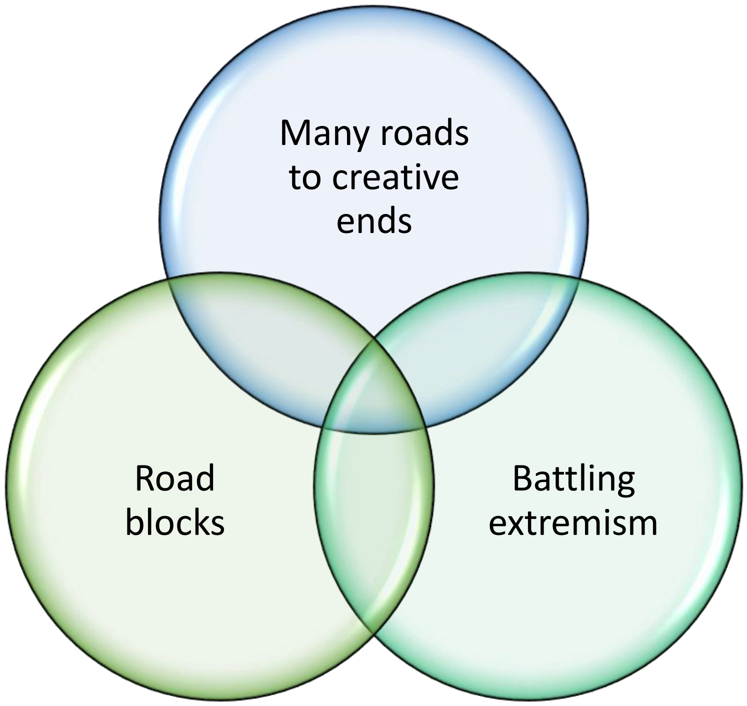


Fig. 6. 1 The superordinate themes derived from the analysis

The figure above (Fig. 6.1) illustrates the three superordinate themes produced by the analysis. The first described the variety of children's routes to creativity in terms of varying states of concentration and distraction. The second described the numerous difficulties associated with decisions and judgments which are an integral part of the creative process. The third described the risks of creative failure at extremes (too much or not enough) control. These superordinate themes were derived from eight subthemes, as shown in Fig. 6.2, which are described in full below.

Superordinate theme 1: Many roads to creative ends
Theme 1.1: Concentration is not a monolith
Subtheme 1.1.1: Hard problems need hard concentration
Sub-theme 1.1.2: It's different from maths
Sub-theme 1.1.3: It's all about the balance
Theme 1.2: Distraction is two faced

Superordinate theme 2: Roadblocks
Theme 2.1: Not panicking but…
Theme 2.2: Letter of the law
Sub-theme 2.2.1: Balancing instructions
Sub-theme 2.2.2: Judgment day
Theme 2.3: Battling inner voices
Theme 2.4: Wait, what is creativity?

Superordinate theme 3: Battling extremism
Theme 3.1: Precarity of focus
Theme 3.2: Drying up vs overflowing

Fig. 6. 2 Thematic map giving overview of themes at different levels

Superordinate theme 1: Many roads to creative ends

This describes the manifold approaches to 'the creative process', the finding that there is not one unified consistent process for all. Even within an individual, modifications in process can arise due to changing constraints, time pressure, idea abundance and stress. Creativity is painted here, not as a predictable machine in which specific substrates are added and established processes executed to produce optimal ends; instead, it materialises as a dynamic, mutable process which bends, flexes, and sometimes fails in response to myriad changing needs. Subthemes relating to concentration and distraction illustrate how this is true for control / focus, which is deployed in ways which can appear contradictory, to achieve creative goals.

Theme 1.1: Concentration is not a monolith

Description: Concentration has many forms and definitions, with variability both within an individual over time and between individuals

All children were asked about their state of concentration while doing the test. Given the commonalities of their experience – all were doing the same task, in the same setting, for the same length of time, with the same past experience of similar tests - there was remarkable variability in their responses. For some the test required deliberate, hard concentration, while others barely even noticed concentrating. Some differentiated between 'tight' and 'loose' concentration, with descriptions suggesting that, for some, concentration and distraction are not necessarily opposite ends of a continuum. In all the quoted responses that follow, children's words have been reproduced verbatim.

Subtheme 1.1.1: Hard problems need hard concentration

For some children, the test presented a real challenge. The only way to meet it was with total and exclusive focus.

> Panda: My concentration was pretty full on because it was quite hard and I find found it a bit difficult so my concentration was 100%

> Jamie: Really hard like…like its SATs or something

Many children compared their concentration to their normal classroom concentration; some trying for a level of concentration they recognise from lessons and others exceeding it.

> Rabbit: Erm I would say it wasn't I'd say it wasn't as good as I am in class with the concentration… so I'd say my concentration was probably about 7 out of 10

> Nutella: I think I'm concentrating differently and harder

Sub-theme 1.1.2: It's different from maths

For other children, things were very different; they spoke of a looseness of concentration and even a state of relaxation. The narrow focus needed for questions with a right answer (as in maths), did not feel appropriate to them here. Rather, what was appropriate was an openness and receptivity to ideas which might emerge unpredictably and from anywhere.

> Parrot: Relaxed and calm and erm and my mind would be so relaxed that it would just think of everything that I watched before had done at home and then I'll just write it down…Like erm it didn't have to work very hard

> Cat: I was kind of just thinking of playing with it in my mind so kind of not concentrating

> Medea: Maybe quite loose concentration if you know what I mean because I'm like trying to get loads of ideas at the same time…when I'm doing loose concentration my brain's like ooh there's one there's a connection like catching fish … If I've got really hard concentration I can only see like one at a time

Sub-theme 1.1.3: It's all about the balance

Several children articulated the fact they could access different styles of concentration in their thinking. They exercised choice in their approach, whether in modulating the speed they worked at, adjusting the focus of their visual attention, or altering the mode of concentration itself.

> Dr Dolphin: I was kind of rushing myself but I was also kind of taking it slow...I kept on thinking of the saying erm… erm… slow and steady wins the race and I just kept on thinking about that…yeah but I also felt a bit like erm… a bit like the erm… the hare in the race sometimes

Guinea pig: Yeah… yeah … I kept on like… I think… I'm I don't know erm… I did keep on looking back and towards the other things but then when I thought of one I kept on looking at it for a while and then I looked away again

Medea: I just probably I stop for a sec for a few seconds and then I just go back and then it's just different concentration yeah… it's a bit weird cos my brain just changes it all by itself… and erm I think it just knows if it needs loose concentration or not

Finally, one child positioned control and spontaneity as synergistic – for her, a lack of noise allowed for the concentration needed to allow ideas to spontaneously 'pop up' and then to be evaluated in a controlled way.

Parrot: I prefer when it's quieter… because then I can like concentrate and I could think of words that like pop into my head and then I could just write it down and make sure it makes sense

Theme 1.2: Distraction is two faced

Description: Distraction can intrude on focused search - or can act as a source of new ideas

Distractions were seen by some children as the enemy of concentration.

Nutella: You kind of block out everything else so you kind of make sure you're just doing this and you focus on it a lot

Panda: I kind of noticed them [banging noises] but I was trying my hardest to block them out cos they're a little bit distracting

Some hinted at the fact that concentration is what is expected at school, the correct approach,

Ammara: Erm I wasn't distracted at all I think I was pretty good

While others saw distractions in a more productive light.

> Pickle: Listening to the noises as well like there was banging of doors and stuff…They helped me think of different things as well so like the door slamming think of doors and locks and stuff so lock picker

This theme illustrates the diversity of approaches in the deployment of concentration and distraction to achieve creative goals. Concentration levels varied greatly from person to person, with some needing 100% focus and others a much looser, calm, relaxed mindset. But it also varied within individuals: several children described either spontaneous or intentional modulation of their concentration level during the test, often expressed through a change in thinking pace – taking it slow, stopping, rushing forwards – in response to changing moment-to-moment demands. The ability to block out distractions, often seen as a core aspect of inhibitory control, is a double-edged sword here: for some children, distractions were nothing but a hindrance to clear thinking, while for others they provided useful substrate for creativity; blocking them resulting in negative creative outcomes.

Superordinate theme 2: Roadblocks

Many responses spoke to the difficulties associated with having to be creative on demand. Some involved the pressures of the creativity test itself. Others concerned questions of interpretation and uncertainty about how creativity might be assessed – both from the outside looking in and the inside looking out, with some children articulating internal battles about how best to judge candidate ideas. Finally, there were themes concerning reflective questions about what creativity actually is. Together, the elements within this theme suggest that, to a considerable extent, performance outcomes in creativity tests are determined by how an individual chooses to interpret and work with task instructions. This might be of particular relevance to the AUT since its task instructions are especially open to different interpretations.

Theme 2.1: Not panicking but…

Description: Time pressure is just that – a pressure. It might spur on or it might paralyse but there is no pretending it is not there.

Even in a familiar setting, with a known adult, a familiar test, reminders that there are no right answers and encouragement to have fun and play, creativity tests are still tests: artificial, stressful, and plagued by the sense of a ticking clock.

> Koala: I got sort of I was kind of like I wasn't panicking but I was just sort of speeding up like just dadooodoooodoo like yeah
>
> Elton Van Gogh: I just thought at the beginning I just thought like I was just completely lost and then I thought and then like then I added to my mind that I had to be really quick and I was like oh my gosh
>
> Rabbit: I thought oh I've only got a few more minutes and I don't really know what I'm going to do so erm I I kind of... my mind was kind of like boggling
>
> Nutella: You're kind of just scrambling through your mind
>
> Dr Dolphin: Well because I was kind of rushing I didn't really have time to breathe

Theme 2.2: Letter of the law

Description: Completing the task means assessing sometimes conflicting demands – first, the quantity / quality trade-off and then individual judgement about what constitutes high quality.

Is it better to spend 3 minutes on one brilliant answer or ten average ones? And to what extent are children cognisant of the trade-off? There is a genuine dilemma here with many interpretations and different output implications. Even once a decision (deliberate or otherwise) has been made about whether to favour quantity or quality, there are many subsidiary decisions. Should an idea which is a little unusual but highly functional be prized more highly than one which is very innovative but unlikely to work? Who is the audience for these ideas and who will be the judge?

Sub-theme 2.2.1: Balancing instructions

A difficulty with the Alternative Uses Test, discussed in Chapter 2, is that its instruction, 'Produce as many unusual ideas as you can' points in two directions simultaneously: 'as many as' suggests maximising quantity while 'unusual' points to maximising quality, through rarity. In a limited time period, it is not usually possible to do both (although some children's approach might mean that the best route to good quality is via large quantity). It largely comes down to personal whim or judgment as to which to favour.

> Ammara: I remembered like it's supposed to be not just like not just like really good ideas it's supposed to be like lots of ideas

> Panda: When I think I was doing the erm hairclip I thought like that would be something that somebody would do and I thought I tried to think of something else which is similar to a hairclip but I couldn't really so I decided to just stick with it and you said do a lot like try and have a lot of answers I was kind of like saying to myself try and get a bit more done or something yeah

Nutella: I think because you give us me less much less time I think of much more improper stuff…

Dr Dolphin: I just wanted to get loads of ideas but I also wanted to think of ideas that no one had said

Pickle: There was one which was I can't remember what it was but I didn't write it down because I thought probably everyone else would have done it too

Sub-theme 2.2.2: Judgment day

The perceived rules of the test and the quality / quantity trade-off are one problem. For some, there is the additional burden of self-imposed constraints as to what constitutes a legitimate idea. Are they allowed to use more than one paperclip? Can they add it to something else? Does their idea have to actually work? The definition of creativity requires originality and value; while the quantity/quality trade off centres mainly on the originality dimension, this theme is chiefly concerned with value.

Elton Van Gogh: There's so many ideas I thought of like I thought of loads but they're all so pointless...like a hairclip it's like why do you need that I thought like but why would you need that it's just like waaah

Dr Dolphin: I was thinking about that I was thinking maybe it could be like a something that you could clip onto a bag like a keyring but it would fall off very easily…but now I'm regretting that I didn't do that cos its actually really cool

Ammarra: I half thought of it because it says a paperclip and I was just like I need lots of a lot more than one paperclip

> Amber: I thought about like different ways they could hold things together but then but then I thought cos they're already holding things together it wouldn't really be a new idea

> Medea: Well maybe the one about using it as a kayak I was like that won't work because not it's not like erm it's going to get loads of water in that's one I probably discarded

A change in constraint, imposed or self-generated, occasionally led to a change in the perception of value. Elton Van Gogh, who was previously preoccupied about whether an idea would work in practice, described how this stricture was loosened if he thought of an idea as 'art'.

> Elton Van Gogh: Art's a less strict kind of not subject but like area of like like it's like a less like with art you can really do what you want… with art you can do loads of different things so that's why I think that's why I was less strict

Theme 2.3: Battling inner voices

Description: personal judgment about what is a good or bad idea is sometimes played out in 'battles within one's own head'.

This theme is similar to 'Judgment day' but here the battling inner voices describe deliberate involvement of higher control or metacognition. The questions are focused less on speculation about what, externally, might be deemed good or bad, allowed, or disallowed, and more on one's own, internal dilemmas.

> Ammara: Normally when I'm about to do something I think if it's like a good thing or a bad thing…there are two voices in my head and one of them's doing the good thing and one's doing the bad thing kind of like in the movies… I thought I shouldn't do it but then the one of the voices in my head told me I should do it anyway so I just did it

Nutella: It's kind of having an argument with me… I was kind of debating with the other me whether I should do it

Theme 2.4: Wait, what is creativity?

Description: How children rate their 'best idea' gives insight into how they define 'best'.

For some it is originality, for some surprise, for others functionality. Some also recognised there was a balance to be struck between competing criteria and selected an idea which succeeded on multiple dimensions. Several children emphasised originality:

Amber: A good idea is something that's very unusual and very different to a paperclip's normal use

Koala: Ukulele capo…I don't think anyone would choose it and it's you wouldn't really think of a paperclip being used for it

Some were more concerned with value, often measured in terms of functionality:

Rabbit: I feel like a bookmark erm would work perfectly well

Pickle: My favourite one I did was probably a lock picker…Because… so sometimes because I'm quite naughty often I get sent up to my room and I'm always trying to pick the lock to get out but it hasn't worked yet

Guinea pig: I like the zip one the most cos like it's one that you couldn't use that many things apart from it [a paperclip] to use

And some considered multiple dimensions concurrently:

Medea: It's probably the most creative...I mean like not not like you see them every day… and because it would work as a surfboard but most people think it wouldn't

Nutella: This is the strangest one out of all them definitely but I think it's the most unique a wallet closer because it sounds really weird but if you kind of stuck it into the like leather on that side and then had like a little handle there and put it in put it through there it would kind of like secure it

Dr Dolphin: The mini clothes hanger…because you can make like so many and I just find them really cool cos you could like put them on your own like mini shelf

Pickle my bunions: Probably the lilo for ants…cos it's it's like interesting figuring out how would that be possible and thinking of the answer and you find that that's so unusual how did I think of that

Superordinate theme 3: Battling extremism

A dearth of ideas is always a problem for creativity; so too, albeit more rarely, can be an overflow. If ideas tumble out too quickly there can be insufficient time for quality control. Extremes of focus / defocus can also cause ideation problems – whether through paying too much attention or not enough.

Theme 3.1: Precarity of focus

Description: Looking through too narrow a lens can mean losing ideas at the periphery. The 'right amount' of focus is hard to maintain.

Koala: When I try to focus a lot I just forget it within the first second

Medea: If you think too long too much about like the ones that are too good you're going to lose like all the good ones

> Pickle my bunions: After say 3 minutes I just zone out and I just think that I'm in my own little world please don't share this with my teacher

> Dr Dolphin: I felt confident at the start but then I started to lose ideas...when you have an idea you kind of forget it

Theme 3.2: Drying up vs overflowing

Description: Typically, in the AUT, the rate of ideation starts fast and slows with time, the well-established 'serial order effect'. This was the most common rate effect seen here, though there were notable exceptions.

Most children reported a gradual slowing as their ideas emptied out. Some even found themselves physically scouring the room for extra ones.

> Panda: [Towards the end] I couldn't think of any more ideas I was thinking like really really hard and no ideas came into my head I was looking around I was looking under the table as well

> Guinea pig: It was getting much harder I think I would have only got a few more

> Squish: I was definitely ermmmmm slowing down

But this was not always the case, with more than one child reporting that they were just getting going, as a trickle became a flow, and ideas inspired new ideas.

> Ammarra: I think with more time I think I would have come up with more ideas…

> Medea: The first one was hardest and then it got easier as I got like more because like my brain was making connections and stuff… It feels quite quite it feels stressful because cos you've got all these ideas coming at once

Children's descriptions demonstrate that, although a wide range of creative approaches can bear fruit, that doesn't mean 'anything goes.' In particular, there are dangers at the extremes, with too many or too few ideas and too much or too little focus both risking loss of creative productivity.

In summary, the thematic analysis pointed to diversity rather than unity in how children deploy EC in their creativity. There were descriptions of different types of concentration, from tight to loose, effortful to effortless, both within and, even more so, between individuals. Similarly, there were diverging views about concentration-relevant factors, such as distractions and mind-wandering, which were contrastingly positioned as beneficial or detrimental to creativity. Time constraints and other pressures, such as feeling stuck, sometimes led to more controlled approaches, and were often coupled with indecision about rule interpretation, whether to favour quantity or quality, and how to judge originality. Finally, there was evidence of failure at extremes, with children reporting both an overflow or, more commonly, a dearth of ideas related to, respectively, excess spontaneity and excess control. These themes will now be further illustrated with selected individual case studies.

Case studies

The following idiographic thematic narratives, each focusing on a single child, are designed to give richness and texture to the themes above. They demonstrate some of the individual variation in how themes play out for different children. There are four narratives, chosen to reflect different approaches. The set of each child's AUT responses and resulting scores (which will be fully detailed in Chapter 7) are included to give further context to the narratives, with the group means also included for reference.

Medea

AUT fluency: 23 (mean 7.5) *Originality*: 3.01 (mean 3) *Flexibility*: 16 (mean 5.81)
Responses: nose ring, hair clip, chain, a massive one as a surf board, a two seated swing, door skeleton key, fork, light switch, catapult, weight, bar, railing, paddle, mousetrap, fish hook, pole, sign post, arrow, bridge, two sided tightrope, ring, button, whisk

Medea showed an astonishing level of fluency, the highest in the sample by a large margin. She showed no sign of slowing even at the end. This fluency seems to be achieved through a particular mode of concentration and the sequential nature of her ideation, with one idea catalysing others 'cos normally when I do stuff I think of something then I think of something quite similar afterwards'.

Her description of the defocused concentration needed for this kind of task is very evocative, 'maybe quite loose concentration if you know what I mean because I'm like trying to get loads of ideas at the same time… my brain's like ooh there's one there's a connection like catching fish…' In describing what this feels like she says 'It feels quite stressful because you've got all these ideas coming at once…when I'm doing loose concentration… I feel like there's netting in my head and it's letting all the ideas in at once like a tsunami'.

She contrasts this with 'hard concentration'; 'if I've got really hard concentration I can only see like one at a time…' This sort of concentration might be used 'probably in maths cos yeah there's only one answer in maths'. Modulation between these different types of concentration is mostly automatic. 'It's probably when…when I just probably stop for a few seconds and then I just go back and then it's just different concentration … it's a bit weird cos my brain just changes it all by itself…' But there are clues as to when a modulation might be necessary which come from the type of problem being tackled, 'I think my brain can tell when I see a question…if it's got like "many" or "lots" in it, it will probably need loose concentration…and then if it's got like one answer like "7 x 6" or "what is the name of this character" I'm doing not loose concentration I'm like narrowing it down.'

When she is stuck, fiddling with her hands can help to get out of a rut, 'I like to fiddle quite a bit when I'm stuck…It's just like concentrating on something else and coming back and then ha! …I'm looking at it with like clean eyes.'

There is a whole cocktail of places from where ideas emerge – e.g., with the surfboard idea, at first, she said, 'I have no idea where that came from'. Then added 'cos I think I looked at this [the end of the paperclip] and cos it's quite similar to a surfboard and you could stand on that and just go weeee'. With further effort to identify the provenance 'I think I probably just actually I think I just know now cos a chain cos I was thinking of a chain ferry in the water…yes I was thinking to do stuff with water like chains and anchors that's probably where that came from'.

She personified an approach to creativity seen in ideational environments, in which judgment is deliberately deferred, on the basis that sometimes a bad idea is a stepping stone to a good one. She proposed a mousetrap (score 3) an idea whose efficacy is hard to see but this was followed by a fish hook (score 4) a high-scoring idea which arose as a direct result of the weaker one, 'I think I definitely got related to that because you normally come and tempt them with something to come and get the mouse and I thought ah! You could do that with fish as well'.

There was a general feeling of pleasure and openness and several incidents of mini eureka moments: she voiced 15 'Ah!'s, 9 'Oh!'s and one 'Ooh!'.

Elton Van Gogh

AUT fluency: 3 (mean 7.5) *Originality*: 2.92 (mean 3) *Flexibility*: 3 (mean 5.81)

Responses: use it for taking out a simcard in a phone like a pin, connect to your bag to put on lots of keyrings, use it to make crazy artwork by putting paperclips together or using them to rip things like paper

Elton Van Gogh produced just three ideas, the lowest fluency in the sample. The rate of production started slow and grew even slower 'There's nothing else to look for…I think I'd think of not many more and not very good ideas.' This low fluency seems to be explained by two main factors – the first, a degree of self-limiting worry about being unable to come up with ideas 'I was saying over and over in my head what do I do what do I do… I was just at a lost for ideas because I just thought that a paperclip really is like a random thing and that I couldn't really work with it'. This made it hard for him to get going and when he did, he was preoccupied by his performance, 'I felt like in my head there was like a clock ticking and I was like I was like I'm running out I'm running out of time'. There was little ability to 'let go' sufficiently to allow ideas to come, suggesting high self-inhibition.

The second part of the explanation was a very high level of self-imposed constraint on what constituted a valid idea - so that even when ideas were conceived, they were often ruled out. The reasons for rejection were various; an idea might be too pointless: 'Well I was thinking like a knife…(but) there's no use in that because it's just making something easy hard'; 'like a hairclip but why would you need that?' or it might not work well in practice: 'you could have like swinging ropes like to connect them together but …I just thought like… there is something in the world called tying knots! You don't need it! that's why a lot of my ideas just like I didn't use because that would be you really don't need'.

There was strict evaluative rigour, 'I was just thinking like what could make the world easier instead of just funner…like like what would I need that for?... but like how?... if you're going to invent something… make it better than what it already is'. This suggests that the barrier to fluency is less in the generation of ideas 'I thought of loads but they're all so pointless' but in their evaluation, so that many ideas which others might have ruled in were instead ruled out. 'This is… it's not hard but it's harder to like it's just like harder to make it work'. The only time when the handbrake was allowed off a little was in thinking of ideas related to art; the constraints were loosened 'because I think art's a less strict kind of… like area … like with art you can really do what you want'.

Parrot

AUT fluency: 3 (mean 7.5) *Originality*: 4 (mean 3) *Flexibility*: 2 (mean 5.81)

Responses: you can use a paperclip for a phone holder if you bend it, you can use a paperclip to draw circles and ovals, you can also use a paperclip with a rubber band and attach it to the paperclip to make a 3D house when you stretch the rubber band

Parrot had one of the lowest fluency levels in the group. All her ideas came from memory, perhaps part of the reason why she felt her brain 'didn't work very hard' and her state was 'relaxed and calm and erm and my mind would be so relaxed that it would just think of everything that I watched before had done at home and then I'll just write it down'. Did her mind wander? 'No! It didn't!'

She had an unusual and effective means of generating ideas likely to be highly original: using sources which she knew other children didn't like. 'I just thought of ideas that nobody would watch cos I watch a kind of erm video that's just about hacks and that some other children just think it's kind of boring'. There was no self-editing. Asked if there were any ideas she didn't write down, she said 'Not really I've written every idea down that I thought of'. This differs from other low fluency scorers who generated many more ideas but ruled most of them out i.e., whose strict evaluation appeared to be the chief explanation for the low fluency. Parrot's rate was slow but consistent and asked about what extra time would have meant she replied 'I would have had more ideas' and proceeded to generate another new one (not from memory) on the spot.

The room, the environment, was used differently from most children who looked for direct ideas – e.g., a paperclip could replace a zip pull on a bag. For Parrot it had a less direct but nonetheless powerful effect on her general affect, 'That's what made me relaxed and calm... Because it was like colourful and erm and then it just popped into my head.'

Dr Dolphin

AUT fluency: 6 (mean 7.5) *Originality*: 3.25 (mean 3) *Flexibility*: 5 (mean 5.81)
Responses: pin, toy mini clothes hanger, tiny football goal, part of a sculpture, part of a picture, peg

One of Dr Dolphin's defining characteristics was the large number of ideas which he conceived but which did not make it on to paper. The reasons were various – some were ruled out for being too similar 'one was erm a part a piece of art but a sculpture is already like a piece of art', for not working well 'I was thinking maybe it could be like a something that you could clip onto a bag like a keyring but it would fall off very easily', for not obeying the instructions strictly 'I remember we made erm bicycles out of pipe cleaners back in year one… so I wondered maybe we could make a mini bicycle but you wouldn't have enough to do that,' or for being too obvious, 'I really wanted to do this one but I didn't know if anyone else had done it and it was a zip'. With hindsight, these were not all judged to have been good decisions 'But now I'm regretting that I didn't do that cos it's actually really cool' and there was a recognition that overall performance could, with less forgetfulness, 'it went totally out of my mind', have been improved, 'Argh! I could have done like a whole list! I just did half'.

The limit to higher fluency seems to lie not in the generation but in the evaluation of ideas. In other words, the processes involved in the creation of ideas are productive but are then over-ruled by the processes driving a harsh inner critic. There was also the sense that the number of possible ideas was finite, 'Now I've used up all my ideas, so I look round the room'.

In contrast to the prototypical serial order effect (in which the most obvious common ideas come first and more unusual ideas come later), Dr Dolphin's early ideas were considerably more original, something he was aware of: 'Well I felt confident at the start but then I started to lose ideas so that's why I I erm my erm erm my fourth and my fifth one aren't that erm aren't that erm imaginative.' One might speculate either that these early ideas were 'allowed out' before the inner critic gained too much sway or that ideas previously disallowed for being too obvious were later allowed once time pressure was felt.

He reached for novel prompts to his creative efforts, for example, being led by a sense of social purpose; 'I just think about all the people in my class that love football and I'm like well I could do a football one even though I hate it so much and then I just it just popped up in my head'.

Descriptions of his concentration allude to the contradictory instruction to produce both lots of ideas and ideas that others won't think of; 'I was kind of rushing myself but I was also kind of taking it slow and erm it makes sense to me but it may not make sense to you I was rushing but I was also taking it slow… I kept on thinking of the saying erm… erm... slow and steady wins the race and I just kept on thinking about that…yeah but I also felt a bit like erm… the hare in the race sometimes'. These two factors were attributed to different parts of the body 'I was rushing in my head and I was thinking I have to get this done but then my hand was just going slow cos I need to think of more ideas'.

His approach to getting out of ruts when stuck (which feels 'very boring') was quite positive and suggests a relaxed rather than highly controlled approach, 'I just think about the stuff that I like and… I relax and take deep breaths.'

The idea he judged his best was 'mini clothes hanger' (score 3.75) rather than 'tiny football goal' (score 4.75) which was the single highest scoring response in the sample.

Discussion

This study set out to analyse the processes involved when children complete the most commonly used test of creativity, the AUT. The findings showed that children approach creativity with highly variable levels of concentration; this pertains to trait differences between individuals but also, as shown by some children's descriptions of moment-to-moment changes in concentration, to state differences. Similarly, children differed in their attitudes to distraction and mind-wandering, with some seeing these as detrimental and some beneficial to creativity. Questions of interpretation were a common theme, with many contrasting judgments about what constitutes creativity, whether to prioritise quantity or quality and how best to judge quality - all of which decisions have implications for fluency and originality. Impediments to creativity included excessive control (which blocked potential ideas at various stages of their progression), excessive spontaneous thinking (which limited thorough evaluation of ideas) and a sense of pressure, mostly caused by the time limit, which was strongly felt by nearly all participants. Nearly all children agreed that, as a stimulus object, a paperclip was harder than previous stimulus objects (water bottle, pencil, sock); this was attributed to its small size, a lack of existing ideas from memory of previous uses (compared to the other objects which they had seen used in many ways) and its specific, narrowly-defined function.

The question of whether there is an optimal way to approach creativity will be addressed in the next chapter – when we look at scores through the lenses of alternative creative approaches. In doing so, it will be important to remember that there are many other factors which contribute to creative success which have not been measured here – personality and temperament, mood, motivation to work in a particular domain, stress, tiredness, self-consciousness, engagement with the specific test and much more. How children deploy control is one aspect among many.

Turning to our specific research questions,

- Is there further evidence of individual variation in approaches to creativity, including state and trait differences in the extent that control processes, spontaneous processes and flexibility are deployed to creative ends?

It should perhaps first be noted that, taking a 'macro' view of control, there were many consistencies between children: all children stayed seated, worked throughout the whole three minutes, did not talk during the test, did not doodle or write anything except the responses asked of them – in other words, they all completed the task according to instructions. At a basic level, then, were similarities in how children approached the task. When we look in more detail at the cognitive aspects of how they engaged in it, however, we see differences. The findings support the idea that there are 'many roads to creative ends' this emerging as the dominant theme of the analysis. The idea of there being a range of approaches is strongly suggested by scores alone - it being highly unlikely that someone who produces 23 responses and someone who produces 3 are doing so by the same processes just with varying speed. The qualitative evidence enriches our understanding of what those different approaches might be – with some children taking a 'dripping tap' approach which emphasises generation and productivity as the best route to originality and value, while others take a much more controlled approach in which each nascent idea is heavily scrutinised and critiqued.

- Is there evidence that a high level of inhibitory control has detrimental effects on creativity?

Inhibitory control, as previously discussed, takes many forms (Munakata et al., 2011; Nigg, 2017). Here it was evoked in sensory form (e.g., to block out distracting noises), in cognitive form (e.g., in functional fixedness leading to a failure to ideate or in ruling out ideas not deemed good enough) and in behavioural form (e.g., sitting quietly and still). Again, at the broad level then, all children deployed some level of inhibitory control in order to successfully sit and complete the task, with no children 'failing' at this fundamental aspect of control. There was also some evidence that inhibitory control might have benefitted some children in more specific ways, such as in helping them to achieve the focus they needed to allow ideas to emerge spontaneously.

On the whole, though, there was more evidence that high levels of inhibitory control led to a reduction in creative output: many children reported having ruled out ideas which, had they kept them, would have led to higher scores, certainly for fluency and likely also for originality – for example, an idea ruled out by Dr Dolphin was a 'mini bicycle', a unique response within the sample. Several children also exhibited inhibitory control in their self-imposed constraints on what constituted legitimate ideas – Elton Van Gogh was perhaps the prime example of such an approach, in which it became almost impossible for ideas to measure up to the strictures and very low fluency was the consequence. The role of inhibitory control in blocking distractions is difficult to evaluate; some children reported that blocking was necessary to allow the concentration necessary to generate new ideas while others reported that the distractions themselves evoked new ideas. We can only speculate about what the effect on an 'inhibiting' child would be if they did not deploy this inhibition – would 'allowing distractions in' lead to new ideas or interfere with their chosen creative approach altogether? In a similar vein, it is difficult to decipher, without further research, whether individual differences arise deliberately, through voluntary selection of a particular strategy, or whether they represent the only option for a particular child. This distinction is important in guiding potential strategies for improving creativity, particularly in determining whether approaches based on encouraging alternative strategies are likely to be successful. Can an individual shift their chosen approach? This brings us to our next question. Is there evidence that a high level of flexibility has positive effects on creativity?

Flexibility is also multifaceted (Ionescu, 2012, 2017; Nijstad et al., 2010; Zabelina & Robinson, 2010a), here operating at a micro level e.g., facilitating the shift to new ideational categories, and a macro level, e.g., facilitating a shift between styles of thinking or types of concentration. As in the previous, more naturalistic qualitative study, several children here also spoke of a modulation, whether deliberate or spontaneous, between different styles and speeds of thinking, suggesting that flexibility is an important component. This converging evidence regarding the central role played by flexibility in the creative process will be considered more precisely in the next chapter, when data triangulation will allow us to look at the association between flexibility and creative performance.

- Is there evidence which helps explain the apparent fragility of originality?

Children's reports suggest myriad idiosyncratic features which can influence creative output, some of which likely contribute to the fragility of originality. At a broad level, children might feel uninspired by the stimulus ('A paperclip… I couldn't really work with it'), panicked ('My mind was kind of like boggling'), pressured by time, ('I didn't really have time to breathe') or be uncomfortable working alone ('it feels a bit weird to be doing things on your own'). Added to these uncertainties, which might affect both fluency and originality, are specific individual decisions about whether to emphasise quantity or quality i.e., whether originality should be a focus at all. Children differ in their starting positions on this (e.g., 'It's supposed to be not just like really good ideas it's supposed to be like lots of ideas' vs. 'I didn't write it down because I thought probably everyone else would have done it') and might also change their view as time goes on; for example, an intention to prioritise only exceptional ideas might cede to a decision to include more commonplace ideas later in the task ('With the key picker, I thought… I've only done four so far so I might as well just do it').

The problem then is not only that good original ideas are hard to come by, but that the test leads to competing assessments of the extent to which originality is the goal. Furthermore, even if it is the goal, there might still be uncertainty with and difficulty in achieving it. Requiring children to 'think of ideas that no-one else will think of' demands a high level of understanding both of others and the world; to produce an original idea, children must not only find successful ways of shouldering their way through more accessible obvious or unexceptional ideas and arriving at unconventional ones - but must additionally weigh up the probability that others might have arrived at a similar destination.

These qualitative findings support quantitative findings that originality is a precarious measure and demonstrate the manifold complex reasons why this might be so. Further work could benefit from trying to minimise some of this instability, for example by eliminating the quantity / quality uncertainty through an instruction to focus solely on one aspect. The expectation would be that a 'quantity' instruction would highlight those mechanisms involved in maximising fluency, while a 'quality' instruction could help elucidate specific originality-relevant processes. It would be possible to test hypotheses regarding the role of EC in 'quantity' vs 'quality' creatives. For example, in the quantity condition, greater inhibitory control is likely to be detrimental to fluency, blocking the free and far-ranging associational flow of highly productive generation; in the quality condition, its role could be more nuanced: it might be of benefit in the evaluative phase in barring less original responses, but that beneficial role would only come into play if sufficient candidate responses were available.

Finally, since our ultimate interest is in considering ways in which creativity, including originality, can be improved (by explicit instruction, practice, use of strategies or other means) , it is important to consider whether, despite the complexities, there are commonalities which benefit or dent creative effort. In the following chapter we will consider some systematic features of the creative process, such as a lack of flexibility, which might help explain how originality might founder – and which might, as we shall discuss in Chapter 8, be amenable to improvement.

- Is there evidence of creative failure (in quantity or quality) at either extreme (too much, too little) of control?

Although there was evidence of both, the findings suggest that 'drying up' is more of a problem than 'overflowing' when it comes to ideas. Only Medea, who produced 23 responses, spoke of feeling engulfed by ideas, saying it felt 'quite stressful' with so many ideas coming at once. More often, children spoke of too much focus causing them to 'forget' or 'lose' ideas. Panda described how when she 'was thinking like really really hard' that 'no ideas came', an observation that will chime with those who have had to produce ideas under pressure. It is possible that the stress brought about through the strict time limit of the test, creates an environment where it is harder to access a freer, more spontaneous approach, meaning a controlled approach arises more by default than by design.

Almost all children described feeling 'stuck' at some point during the task, with several giving evocative descriptions of the sort of fixedness associated with excessive inhibitory control that such a feeling can induce ('I think about here I was like argh paperclips I only know one reason for paperclips that's because they're paperclips', or 'Yeah yeah cos I couldn't really think and then… I tried to think and then I thought of ideas that I'd already thought of' or 'I was trying to say like think of a paperclip think of a paperclip but it didn't really help'). Might this sort of blockage be cleared by really strong inhibitory deployment? There were no accounts from children which suggested such a process at play. By contrast, those who effectively escaped being stuck tended to do so not by specific efforts to overcome functional fixedness but by more direct and immediate appeal to novel input from senses or from memory, behaviour more suggestive of greater flexibility; 'To get unstuck like I said I was looking around…and listening to the noises as well', or 'I was like… there must be an idea in this room that will help me yeah' or 'I I kind of thought what else was available to like what else was available what's going on... like what I've done in my life… or like what I'm doing today'.

Again, a quantitatively based consideration of this research question will follow in the next chapter.

Limitations

One of the main limitations of this thematic analysis was that, as with its factor (or principal component) analysis quantitative counterpart, there is a tendency to 'get out what you put in'. Themes arise and are developed from the starting point of particular questions asked. This carries the risk that there are other potentially important themes which remain obscure, not because they are not important, but because they were not elicited in interview.

Other limitations were more specific to how the research was conducted. The test environment presented too many opportunities for ideas available visually, potentially limiting ideas arising from internally directed attention. The choice of a paperclip as the stimulus object was also not ideal, since its nature does not really allow for disassembly, which can be a productive ideational strategy.

Conclusions and next steps

These qualitative data provide the strongest evidence to date that children achieve creative ends through different means, since even in completion of the same task, they reported diverse approaches. Differences extended to their deployment of EC, with some children describing the need for high levels of control and focus to maximise creative output and others the opposite, suggesting excessive control keeps the ideas out rather than allowing them in. The findings build on emerging ideas that changes to EC are likely to impact children differently, depending on where they lie on a 'control continuum' and their level of flexibility in moving from that position. We will now put those ideas to the test, by looking at how different children fared when the level of their EC was altered by training.

Chapter 7. Can understanding the role of EC in children's creativity help predict individual effects of EC training on creative outcomes?

Integrating findings from qualitative and quantitative approaches

Introduction

The previous triangulation study (Chapter 4) outlined the main arguments in favour of a mixed methods approach (Creswell & Clark, 2011; Hesse-Biber & Johnson, 2015; Johnson et al., 2007; Tashakorri & Teddlie, 2009, 2010) as well as some of the ongoing controversies (Guba & Lincoln, 1989; Tashakorri, 2009; Teddlie & Tashakorri, 2008). It also described the pragmatic approach advocated by many in the mixed method field (Johnson & Onwuegbuzie, 2004; Morgan, 2014; Yvonne Feilzer, 2010) as one which essentially sees continua where others see dichotomies: abduction combining inductive and deductive reasoning, intersubjectivity allowing both subjective and objective perspectives and a critical approach to the validity of wider application of *any* findings breaking down an absolute distinction between the specific and the universal (Morgan, 2014; Schwandt & Lichty, 2015; Yardley & Bishop, 2017). The previous study also highlighted the fact that every triangulation study presents distinctive challenges, making transparency regarding assumptions and limitations critically important (Creswell & Clark, 2011; Hesse-Biber & Johnson, 2015; Schwandt & Lichty, 2015; Yardley & Bishop, 2017).

Beyond the theory, the experience of triangulation meant learning practical lessons about the best approach. For example, a major limitation previously involved the many assumptions of validity of comparing qualitative and quantitative data derived from different creative activities, in different environments and under different constraints. This limitation has been minimised in the current study, since all these aspects were correspondent in quantitative and qualitative studies. The wide age range (children from school years 1 to 6) considered in the previous study added uncertainty regarding developmental effects, a problem addressed here by considering a group of children very much closer in age (all children were in year 5). Problems of noise were further addressed by considering longitudinal rather than cross-sectional 'snapshot' measures as before; focusing on individual change over time helped control for some of the many additional unmeasured factors which contribute to creativity (e.g., memory, level and detail of conceptual knowledge, motivation, emotional engagement etc.).

Crucially, in attempting to answer the question of whether there are better or worse ways of 'doing creativity', we can now consider a potential causal role for EC, since we are relating (qualitative) individual approaches to creativity to their (quantitative) individual change in performance over time, with only their level of EC manipulated. The first question posed at the outset of the intervention in Chapter 5 was whether EC training would have any impact on creativity. The answer - notwithstanding the important caveat that changes post training were seen in both EC and active control groups - was yes: creative fluency improved, and creative originality declined. Children had more, worse ideas after the intervention. We can now consider whether this impact of training differed between individuals and how any difference might be attributed to differences in their creative approach.

Aims of the study

Each part of this mixed methods study has had connected yet distinct goals. The quantitative study (Chapter 5) sought evidence on the effects of an EC intervention on children's creative output in divergent thinking tests. The qualitative study (Chapter 6) deconstructed the creative process for a smaller group of the same children, using the same test to reveal diverse means by which creative ends can be reached. This final triangulation chapter aims to bring these two perspectives together. Specifically, it will set out to use data derived from the qualitative study to

- characterise and define specific creative sub types
- make theoretical predictions about how EC training might affect different sub types

- test the accuracy of those predictions using the data from the quantitative study

The first step, of characterising and defining sub types, sought to achieve the most accurate and detailed characterisation of children's creative approach by maximising the use of both quantitative and qualitative available data, whilst 'maintaining the integrity' of methods and findings (Sandelowski, 1995). There are difficulties. In particular, it is hard to resist pressure to yield to the 'lowest common denominator' of triangulation where qualitative data are obliged to submit to quantitative (Hesse-Biber, 2010). The reality is that to properly answer the research question, a common currency is needed, and even though putting numbers to words is a simplification, it is the only real option available. The design of the qualitative study, and the decision to compromise creative freedoms by limiting the nature and conditions of the task (i.e., setting a constrained divergent thinking task rather than a more free and self-authored creative work), sought to minimise the translational journey from words to numbers. This decision, made in the hope of producing more robust findings, comes with its own drawbacks - most substantially, in the impurity of the creativity under study and concomitant uncertainty about the wider applicability of findings. That said, the expectation of clear answers emerging from triangulation were perhaps lower than they were before, given the experience of the complexity and compromises involved in the mixed methods approach.

The process of triangulation remained somewhat complex given the different types of data, which included:

- Scores from the AUT itself. These were the simplest ingredients, being already in quantitative form, but their inclusion nonetheless involved making certain assumptions e.g., that high fluency scores in the AUT were likely to be the result of a more spontaneous approach.

- Information based on the provenance of ideas given as responses in the AUT. Again, this involved assumptions e.g., that ideas arising spontaneously or from memory were likely to elude executive control, while those involving strategic thinking such as in broad use-based categories ('could it be a weapon? could it be a toy?') likely deployed EC.
- The final information, which involved the furthest translation from qualitative to quantitative, came from analysing and quantifying responses children gave about EC relevant processes. These included their state of concentration, their level of distraction, whether they had considered additional responses which they ruled out, and the timeline of their responses – such as whether they showed evidence of the 'serial order effect' (Beaty & Silvia, 2012; Wang et al., 2017).

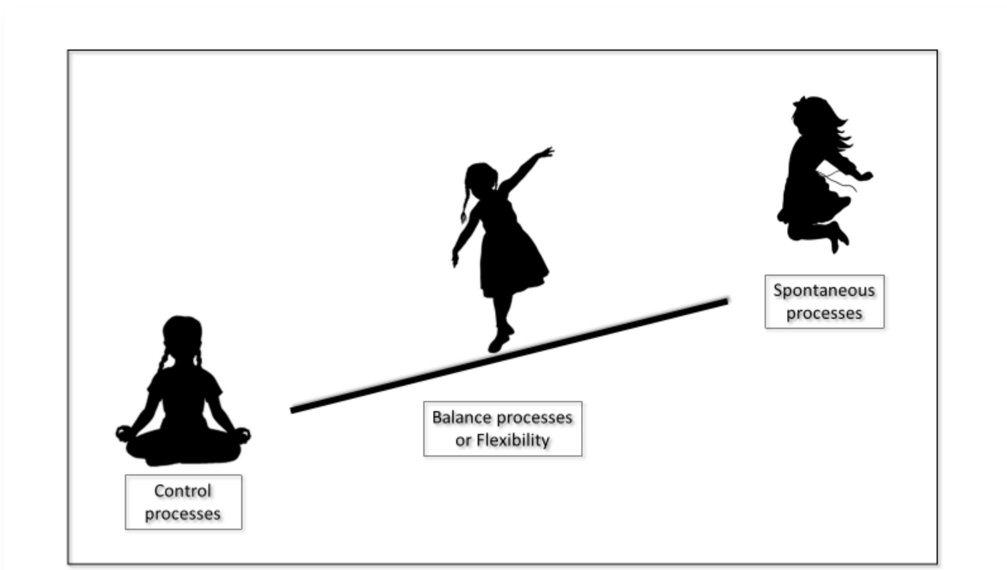


Fig. 7. 1 Illustration of the core components of the creative process

On the basis of earlier qualitative work (Chapter 3), as well as the wider literature (Chrysikou et al., 2014; Fillipetti & Krumm, 2020; Krumm et al., 2018; Mekern et al., 2019; Nijstad et al., 2010; Pringle & Sowden, 2017b; Zhang et al., 2020), the creation of subsets was founded on three key dimensions of the creative process, namely:

- how effectively children tapped spontaneous processes
- how able they were to bring control processes to bear
- how flexible they were in their approaches i.e., the extent to which they could modulate between differing approaches

Methods

This chapter, in terms of foundational method, is a continuation of Chapter 6; the participants and procedure for conducting the AUT test and subsequent interviews - is fully described there. The following section will thus elaborate only on those parts of the methods new and specific to triangulation. The figure below (Fig. 7.2) gives an overview of the different data sources which contributed to the characterising of each child's creative approach. Methods relating to scoring of the AUT, the provenance of ideas in the AUT and broader answers from the qualitative interview will be outlined in turn. These scores, all derived from the qualitative AUT (i.e., the test completed by the small, nested group of children for the purpose of qualitative interview), will then be used to triangulate with the quantitative data from their pre and post AUT scores, carried out as part of the overall intervention study.

AUT performance

For AUT performance, each child's responses were scored as in the quantitative study for fluency i.e., as a simple count of legitimate responses. Originality was scored by four independent raters, who were given a full, anonymised list of responses and asked to score each one. Their instructions were to 'Score each answer on a scale of 1 to 5, where 1 is not at all

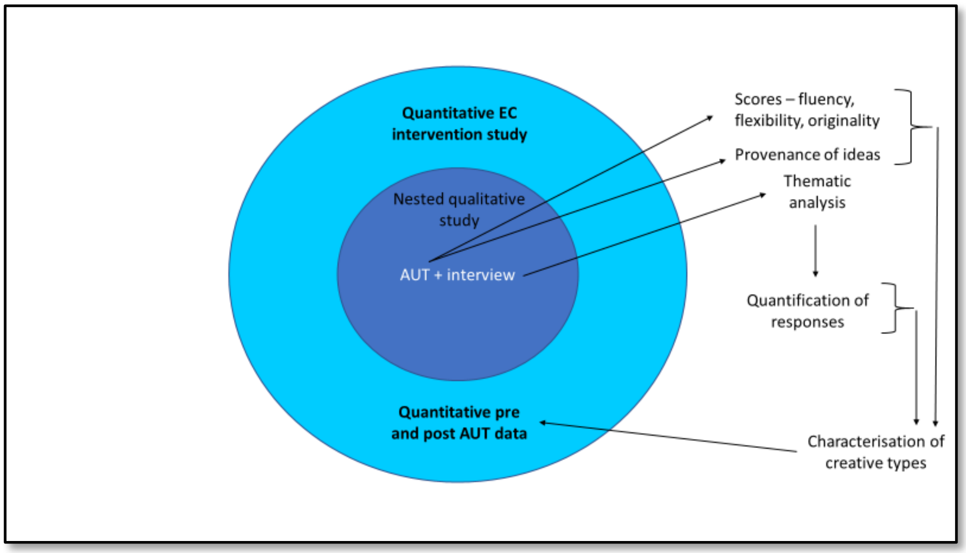


Fig. 7. 2 Schematic showing types and sources of data for triangulation

creative and 5 is highly creative. Take into account your sense of the originality and inventiveness of each response, in one holistic measure.' The rater scoring method (a different method from the main quantitative study) was used because the small numbers precluded reliable frequency scoring (Cropley & Kaufman, 2012; Reiter-Palmon et al., 2019). Inter-rater reliability, calculated using Fleiss' kappa, was good, IRR = .766 ($p<.001$). An additional sub score of flexibility was added, calculated as a simple count of the number of different categories in each child's response set. The score is an indicator of children's tendency to voluntarily switch to a new response category. It is a measure often used in scoring DT tests and was also included to aid categorisation of children into creative sub types.

Provenance of ideas

The next consideration was to try to understand the directly productive part of the creative process. Where did the responses produced and written down in the AUT come from? The approach here was based on Gilhooly et al.'s (2007) think aloud protocol analysis. Each child's written responses became the stimuli to prompt recall, by asking the child where each idea had come from. Responses were first categorised on a per item basis, to later allow each child's most frequently used approach, and their tendency to use multiple approaches, to contribute to category scoring (as outlined below in Table 7.1). Item responses were first classified according to the following a priori coding scheme:

1. Memory use production: specific reference, concurrently or subsequently, to prior knowledge through direct or indirect experience. The reference was either made in response to interview or immediately after, when children were asked to mark any responses which were ideas they had seen or experienced previously.

2. Property use production: retrieving and scanning properties of the object (e.g., 'hard', 'sharp', 'bendable') and using them as cues to alternative uses requiring those properties.

3. Broad use-based production: reviewing the object against broad usage areas such as 'transport' 'weapon' 'art'.

4. Disassembly use production: taking the object apart and producing uses based on one or more dissembled parts.

5. Embodiment production: scanning the current environment to gain input for ideation, or doodling / miming / manipulation or other physical processes to prompt a new idea

6. Spontaneous production: idea 'popped up' without deliberate effort and with no identifiable origin

7. Sequential production: idea directly related to and emerging from a previous given response (usually the immediately preceding one)

A few additional things to note about this categorisation:

- Property use was often used in conjunction with another strategy such as looking around the room. While considering the properties of the object (e.g., a paperclip is small, metal, bendable, can latch on to things), a set of coats and bags in a cloakroom can be scanned for components which might match any of these properties.
- Sequential production. This was sometimes very direct (e.g., using a paperclip as 'a bar' followed by using it 'as part of a railing', in which the first imagined use was almost a constituent part of the second). At other times it was less direct, when a previous idea sent subsequent thoughts in a new direction – e.g., 'hair clip' arose first through property use production but was used sequentially to probe memory for a film in which a hair clip was used as a pick for a lock.
- Disassembly use. Regrettably the choice of object (a paperclip) did not allow for this mode of production in the way that other items might (e.g., a bottle can be disassembled into a lid and a container; a pencil into wood, lead, and paint). A paperclip comprises only one element, moulded into a specific shape.
- Embodiment production. The rich environment where the study took place (a cloakroom) meant that there were many potential ideas to be gleaned by looking around the room.

This might have meant that children were less compelled to look internally for ideas than they ordinarily might be.

These pathways to idea generation were further grouped into categories according to whether they were more or less EC dependent.

- More EC dependent: broad use-based, disassembly, property use production
- Less EC dependent: memory based, spontaneous, embodiment production
- Ambiguous (could be either EC dependent or independent): sequential (follow up to previous idea could be spontaneous or strategic)

In practice, most children made use of multiple approaches, with the difference lying in the dominance of a particular approach. In further analysis, each child's most frequently used approach, and their propensity to use multiple approaches, were used for categorisation, as shown in Table 7.1 below.

Responses in qualitative interview

As well as completing the same creativity test, under the same conditions, children were all asked very similar questions in their post AUT interview. This design was to allow a direct comparison of responses and minimise noise in the qualitative-to-quantitative translation of scores. The questions from interview identified as being most relevant and tractable for quantification in this triangulation phase were:

- the type and level of concentration described (tight / focused, vs loose / diffuse, vs variable)
- whether any ideas were conceived but ruled out (more EC-led approaches being more likely to involve a higher rate of rejection of ideas)

- the presence of mind wandering (more EC-led approaches being more likely to mean children staying on task with less mind wandering)
- the approach to 'getting unstuck' (EC-led approaches pointing to a more strategic, deconstructive approach, and non-EC-led more to memory-based or spontaneous approaches)
- the timeline of idea generation (the classic serial order account - the fluency rate diminishing and originality increasing over time - has a strong EC explanation)

Scoring

In the next step, participants were given scores on the basis of the elements described above. The purpose of this scoring was to characterise different creative sub-types, with two aims: first, for its own sake, to better understand diverse approaches to creativity, and second, to facilitate triangulation by creating quantitative scores from qualitative to compare with the quantitative scores derived from the intervention. After characterising sub-types, predictions were made about the differential effect of EC training on the performance of different sub-types and those predictions tested against the quantitative data. The full basis upon which scores were calculated for 'control', 'spontaneity' and 'flexibility' are outlined in Table 7.1 below.

Aspect of creative process	**High spontaneity approach**	**Spontaneity score**	**High control approach**	**Control score**	**Flexible approach**	**Flexibility score**
Fluency score in AUT	Higher	*5-9: 1pt* *10-19: 2pts* *≥20: 3 pts*	Lower	*<3: 1pt*	*NA*	
Flexibility score in AUT	*NA*		*NA*		Range was 2 to 16	*4 – 6: 1pt,* *≥7: 2pts*
Provenance of ideas	Spontaneity/memory/ embodiment predominant	*1pt*	Broad use/disassembly use / property-based predominant	*1pt*	Mix of approaches	*2 or 3:1pt,* *≥4:2pts*
Concentration	Diffuse, loose, more visual search, more movement, possible use of distractions	*Solely: 1pt* *Partially: 0.5pt*	Tightly focused, ignoring distractions, looking down, little physical movement	*Solely: 1pt* *Partially: 0.5pt*	Description of mixed concentration types	*1*
Ideas conceived but not produced	Unlikely to see	*1pt if none present*	Expect to see ideas excluded for being too obvious, too weird, they won't work etc.	*1 or 2: 1pt* *≥3: 2 pts*	*NA*	
Mind wandering	Likely	*1pt if present*	Unlikely	*1pt if absent*	*NA*	
How to get unstuck	Relaxing, searching memory, using environment as bouncing off point	*1pt*	Strategising: dis-mantling, studying properties, using categories, reversioning previous ideas	*1pt*	Description of mixed approaches and multiple strategies	*1pt*

Aspect of creative process	**High spontaneity approach**	**Spontaneity score**	**High control approach**	**Control score**	**Flexible approach**	**Flexibility score**
Timeline	Still productive at end / getting easier / variable	*1pt*	Easier at start, slower later	*1pt*	*NA*	
What is creativity	*NA*		*NA*		Mention of >1 dimension	*1pt*
Max poss. score		*9pts*		*8pts*		*7pts*

Table 7. 1 Basis on which spontaneity, control and flexibility scores were calculated

Results

AUT performance

As in the quantitative study, there was a great deal of variation in both the quantity and quality of ideas children produced.

	Fluency	Flexibility	Originality
Range	3 – 23	2 – 14	2.47 - 4.00
Mean	7.50	5.81	3.00
Median	6.00	5.00	2.98
SD	4.99	3.60	0.39

Table 7. 2 Whole sample (n=16) descriptive statistics of AUT scores

Examples of ideas which scored highly (≥4) for originality

- Use as a diving board for something small
- A ukulele capo
- Fishhook
- Dip it in ink and use it as a pen
- Whisk
- Lilo for ants
- Tiny football goal

Provenance of ideas

The next part of the analysis was concerned with the directly productive aspect of the creative process. Where did the ideas given as responses come from?

Provenance percentage per category	
Memory	15.8%
Property use	22.5%
Spontaneous	10.8%
Sequential	20.8%
Embodiment	28.3%
Disassembly	0%
Broad use	0.8%

Table 7. 3 Whole sample summary of provenance for given responses, percentage by category, out of a total of 120 responses

Example of each provenance category

- Memory use. 'Pick a lock'. "I've seen loads of movies where they just pick locks with paperclips and I think it's quite cool."
- Property use. 'Tweezers'. "You can straighten it out and then just half it to use it as tweezers cos I mean if you just want to pick something so you need to sample a rat poo you could just pick it up."
- Spontaneous. 'Stick-on nail'. "I just thought of it like that because it just popped into my head and I thought hmm yeah it would be quite ok to do that."
- Sequential. 'Two-sided tightrope' (following on from 'bridge'). "Cos I probably thought ah that wouldn't be a very good bridge because you have to walk like really really delicately like on tip toes like a tightrope and then I thought it's got two sides so it could be like a two-sided tightrope."

- Embodiment. 'Connect to your bag to put on lots of keyrings'. "I looked at your pencil case and … then I thought you could connect loads of keyrings to that."
- Disassembly use. No examples of this (probably because a paperclip does not lend itself to disassembly).
- Broad use. 'Tiny football goal'. "I just think about all the people in my class that love football and I'm like well I could do a football one…and then it just popped up in my head."

Responses from qualitative interview

These interview responses were the foundation of the thematic analysis presented in Chapter 6. The new element here was the conversion of specific qualitative responses to numerical scores for each child, as outlined in Table 7.1 above. The scores for each child, calculated according to those scoring rules, are shown below.

Pseudonym	*Spontaneity* (Max score: 9)	*Control* (Max score: 8)	*Flexibility* (Max score: 7)
Cat	8	2	7
Amber	2	5	7
Koala	5	2	5
Medea	6	5	6
Elton Van Gogh	2	5	1
Squish	3	2	4
Rabbit	2	3	1
Panda	5	6	4

Ammara	5	4	3
Jamie	2	2	3
Parrot	5	3	0
Pickle	5.5	4	5
Nutella	3.5	3	5
Pickle my bunions	7	1	6
Dr Dolphin	3.5	6	6
Guinea pig	4	4	5

Table 7. 4 Scores for spontaneity, control, and flexibility

For ease of comparison, these scores are also represented graphically below.

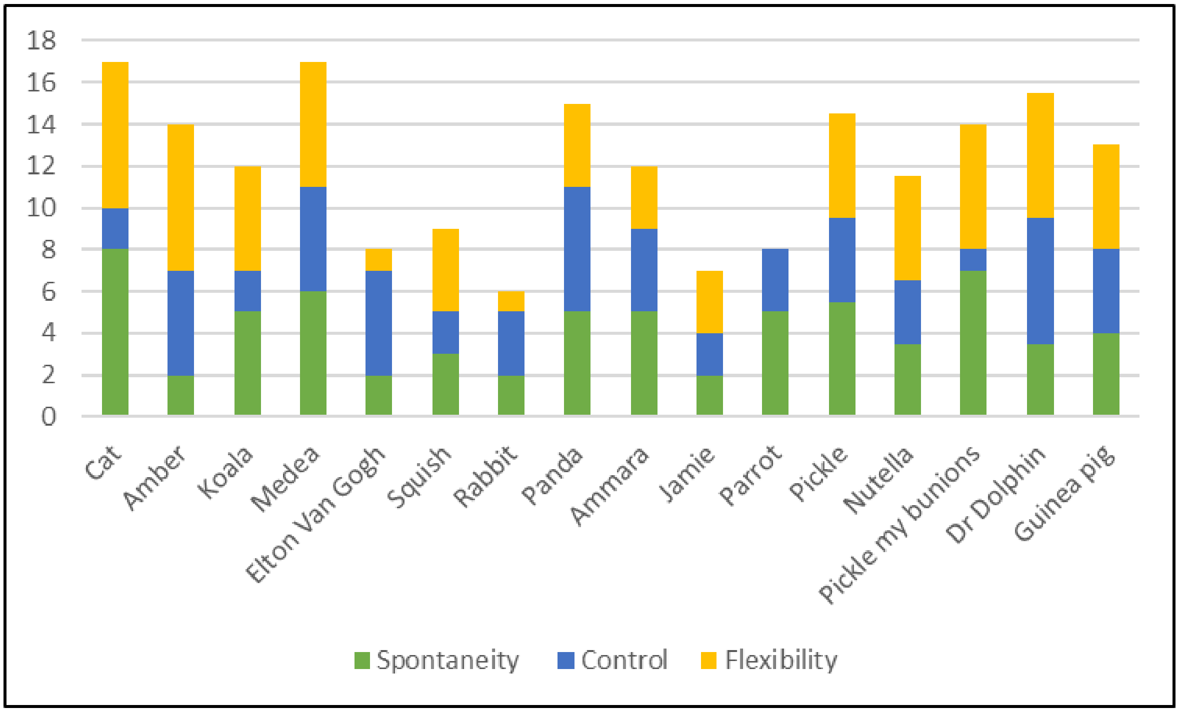


Fig. 7. 3 Scores for spontaneity, control, and flexibility (according to scoring method outlined in Table 7.1) by individual

Delineating creative sub types

The distribution of scores did not immediately suggest straightforward sub-types into which children neatly fell. For example, while high flexibility was generally seen in conjunction with high spontaneity, some children showed the opposite (e.g., Amber, who achieved the highest score for flexibility but almost the lowest for spontaneity). The goal at the outset was to find a small number of groups, characterised according to the main criteria – for example, a 'highly spontaneous group', a 'highly controlled group' and a 'highly flexible group' and several attempts were made to delineate sub-groups in terms of all three main criteria of spontaneity, control and flexibility. It proved problematic. The smallest number of reasonably discrete groups deriving from such a categorisation (even including a 'miscellaneous' group) was six. Even then, groups sometimes included individuals who had widely differing scores on one of the three measures, or groups were so specific as to contain only one member. In short, disappointingly, the resulting categorisations did not seem sufficiently more informative than considering children individually. Returning to the theoretical basis for attempting categorisation, an alternative approach was pursued.

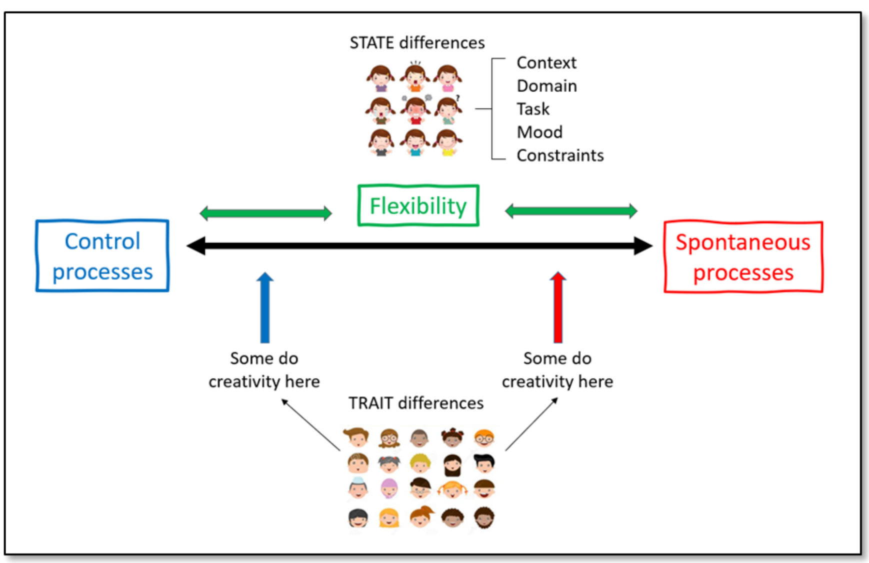


Fig. 7. 4 Model of approaches to creativity, with variability between and within individuals

In the model of the creative process (Fig. 7.4) presented in Chapter 4, the proposal was that flexibility should act as a 'protective buffer' to challenges to creativity; those challenges might come from operating at extremes of spontaneity or control or from new strictures presented by, for example, tightened constraints. This is because better flexibility offers the potential to follow alternative pathways, to reach creative ends through different means – for example, in 'letting go' to pursue broader, more distant associational connections or doubling down on rigorous evaluation (Kennett et al., 2018; Krumm et al., 2018; Nijstad et al., 2010).

On this theoretical basis, a new, simpler categorisation was made, based on each child's level of flexibility. Children were divided into three groups: a high flexibility group (scores ≥ 6), a medium flexibility group (scores 4 or 5) and a low flexibility group (scores ≤3). This gave the following distribution:

Flexibility level	Number in group	Names of children
High (≥6)	5	Cat, Amber, Medea, Pickle my bunions, Dr Dolphin
Medium (4-5)	6	Koala, Squish, Panda, Pickle, Nutella, Guinea Pig
Low (≤3)	5	Elton Van Gogh, Rabbit, Ammara, Jamie, Parrot

Table 7. 5 Assignation of children to creative sub types according to their level of flexibility

The next step was to consider how each sub type was likely to have been affected by EC training. Predictions were limited a priori to performance on the AUT since it offered like-for-like comparison. The original design had allowed for the opportunity to consider children in the EC group and the control group separately. However, since the changes effected in EC and control intervention conditions were largely equivalent, and our sample size here is small, the participants were pooled across intervention conditions. The results of Chapter 5 showed that the overall effect of training was to improve AUT fluency and reduce AUT originality; predictions here were made about differences at the level of the delineated sub types, in light of that bigger picture.

The overarching hypothesis regarding flexibility was that any creativity gains from training should be greater for those with higher flexibility, since they are best equipped to adapt and utilise different approaches. Any losses should be ameliorated since those with higher flexibility are better equipped to find alternate routes. The specific predictions for the three groups were as follows:

High flexibility group. EC training improvements will be assimilated effectively into the creative process, even in those children who tend to ideate using spontaneous approaches (frequently the case for highly flexible individuals), since they have the flexibility to modify their approach. Prediction is thus for tangible gains in fluency through encouraging additional alternative routes to ideation. The general decline seen in AUT originality should be at its least extreme in this group, for the same reason - they are less shackled to one approach. Originality could even improve for those children with high spontaneity and low control since additional control resources could be deployed to better evaluate candidate ideas.

Medium flexibility group. This is the hardest group to predict outcomes for, because it includes children with both high and low spontaneity levels as well as both high and low control and it is likely the balance of these will affect outcomes. Inevitably, predictions for how this group will respond to the training lie somewhere between predictions for the high and low flexibility groups. If this dimension is meaningful for the effect on creativity of EC training, the results for this group should lie in between high and low flexibility groups. So overall, this group should see modest gains in fluency, through the same mechanisms as outlined for the high flexibility group. They should also be somewhat protected against losses in originality, but less protected than their highly flexible counterparts.

Low flexibility group. Low flexibility tends to be seen in conjunction with higher levels of control and lower levels of spontaneity, though this is by no means universal (e.g., Parrot in this group has high spontaneity and low control scores). The prediction here is that EC training is likely to be of least benefit to this group. Not only do they already tend to have low levels of ideational freedom, but their low flexibility also means that they are not very malleable to new approaches. Additional control could mean that those who already have a high level of control experience particularly steep declines in originality, through excessive blocking of potential idea pathways and overly strict evaluation further ruling out candidate ideas.

These predictions concern relative rather than absolute creative outcomes in different groups. It would not be correct, for example, to characterise low flexibility children as having low creativity, since there are so many other factors impacting their creativity – everything from their conceptual knowledge and understanding, to their memory, to their level of motivation and engagement in the task. However, the predictions assume that, other things being equal, those with lower flexibility are likely to be *less* creative.

These data concern a sample of just 16 children, with wide variance in scores. Even though we would ideally look to statistical tools to assess the strength and confidence of findings, a study such as this is not sufficiently powered to do so. By way of illustration, power analysis (Cohen, 1992) using G*Power (Faul et al., 2007) to ascertain the sample size needed to detect an effect size of 0.25 with 90% power and an alpha of 0.05, suggests a sample of 168 would be needed – so we are short by a factor of more than 10. Instead, raw scores and plots (with confidence intervals) will be shown - and these should be understood as being able to give only intriguing pointers and not statistical certitudes. To calculate the proportion of variance explained by the flexibility categorisation, repeated measures ANOVAs were carried out on each AUT variable, with flexibility sub type as the between subject grouping category. Because of the small number, significance levels were not considered. Results for the time*group interaction were AUT fluency: partial η^2= .146 and for AUT originality: partial η^2= .103.

Below, we will first see the data by group, then, for a complete picture, results for individual children will be shown, to see whether group averages are representative of the profiles of individual children who make up each group. A final set of graphs (Fig. 7.7 and 7.8) show individuals within each grouping category.

Triangulation results

	AUT fluency			AUT originality		
	T1	T2	T3	T1	T2	T3
High flexibility group	3.40 (2.07)	7.80 (5.21)	9.60 (5.94)	1.05 (0.68)	1.18 (0.32)	0.95 (0.56)
Medium flexibility group	4.00 (2.00)	8.33 (4.89)	8.67 (4.09)	1.01 (0.51)	1.35 (0.38)	0.66 (0.33)
Low flexibility group	4.80 (5.36)	3.60 (1.82)	6.00 (2.34)	1.17 (0.45)	1.29 (0.62)	0.60 (0.48)

Table 7. 6 Scores for AUT fluency and originality over time by creative type. Means and (SDs).

The general pattern of change in all three groups reflected that seen in the quantitative sample as a whole. Namely, all three groups showed overall gains in fluency and losses in originality

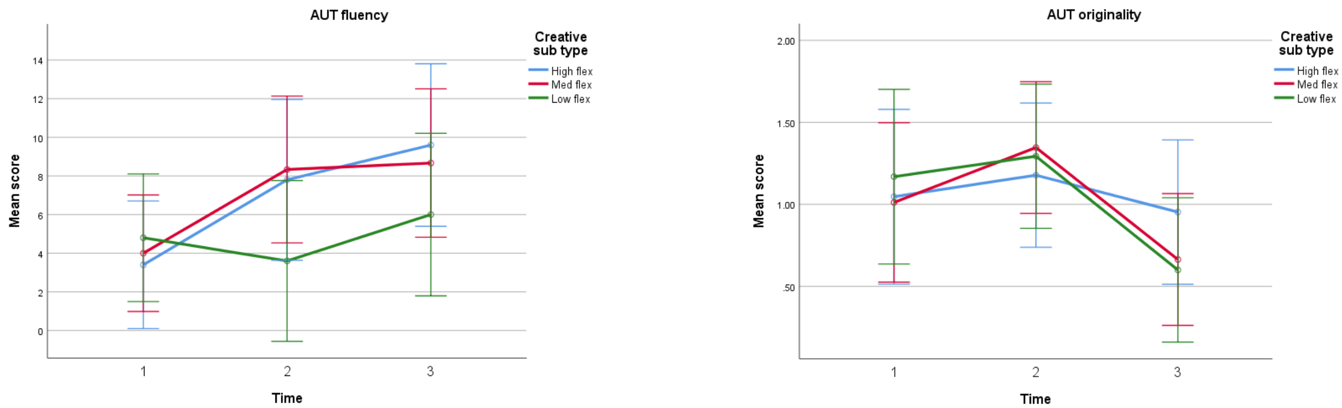
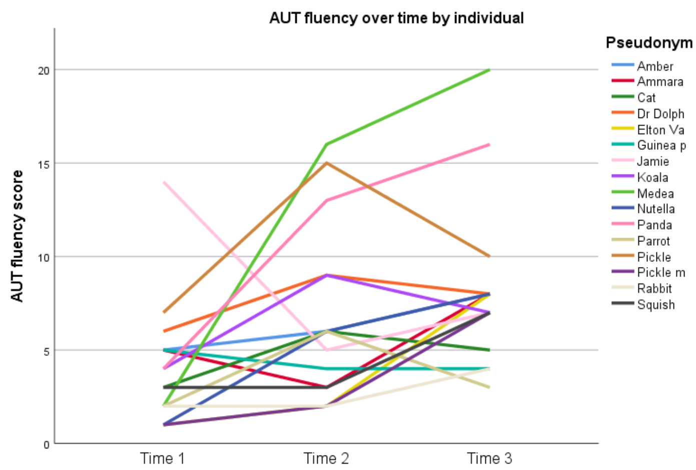


Fig. 7. 5 AUT fluency (left) and originality (right) over time, by creative sub type

between first and final measurement points. However, within this general picture are suggestions of differences between the delineated creativity sub types. At the outset, the low flexibility group had the highest mean fluency and originality. By time 3 they had the lowest scores for both measures. The high flexibility group showed the opposite, starting lowest for both measures and ending highest. The large standard deviations show that there is wide score variation within each sub type, i.e., a great deal of individual difference is present even within the designated sub types and caution over-interpreting results is essential. With this caveat in mind, however, there is some evidence that the proposed 'protective factor' of flexibility does exist and operated in the ways predicted, accentuating the positive EC gains to fluency while ameliorating the negative effects on originality.

The graphs below give a sense of the wide variation in performance change at the individual level. As before (in the full quantitative sample in Chapter 5), the variability in the pattern of change over time appears particularly unpredictable for originality.



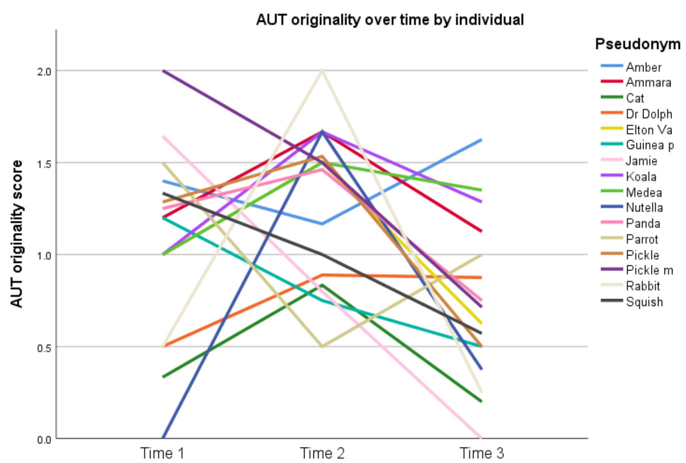


Fig. 7. 6 Individual variation in AUT fluency (top) and originality (bottom) over time

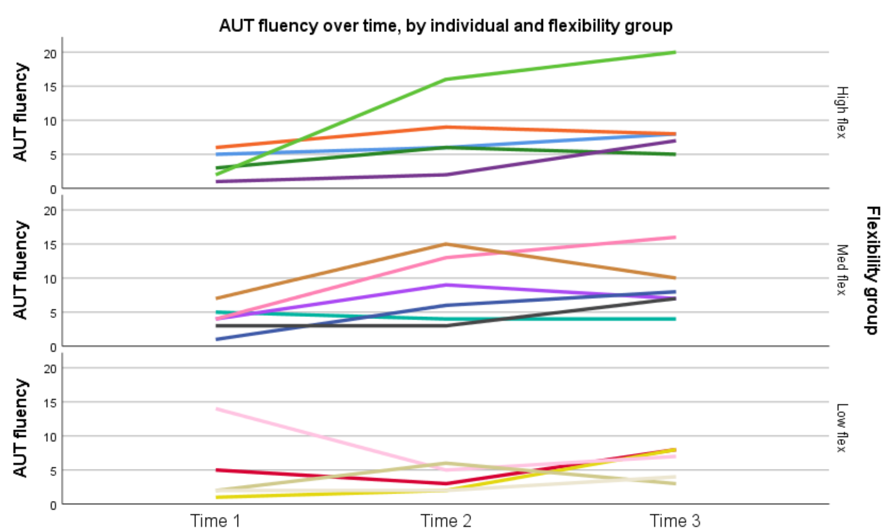


Fig. 7. 7 Group level variation in change in AUT fluency over time, by flexibility sub type

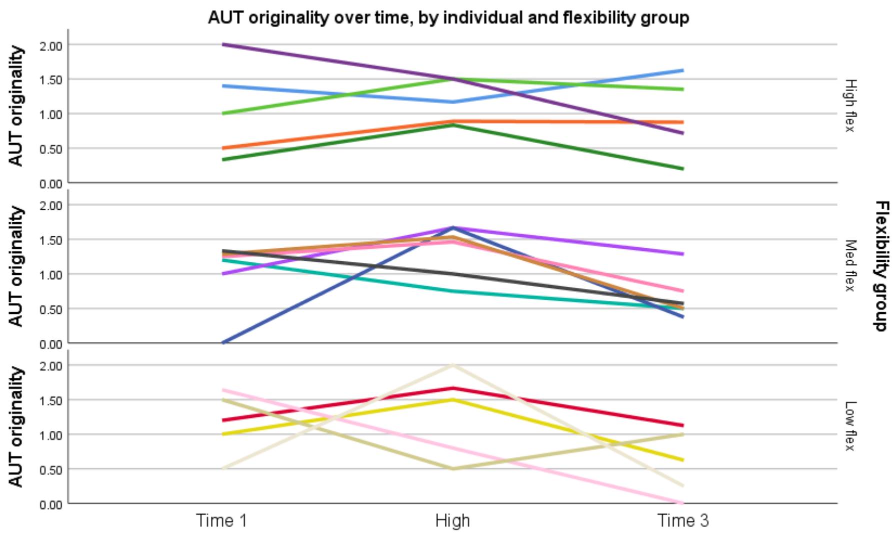


Fig. 7. 8 Group level variation in change in AUT originality over time, by flexibility sub type

Discussion

Triangulation addressed the question of whether understanding the role of executive control in children's creativity could allow accurate predictions to be made about the specific effects of EC training on individual creative outcomes. Building on evidence from the EC training intervention study (Chapter 5) and the qualitative study (Chapter 6), which characterised EC-relevant themes in the process of completion of the AUT, this study brought both data sets together in a multistage analysis. The first step involved characterising and defining specific creative sub types, with creative flexibility ultimately being selected as their key distinguishing feature, based on the theoretical notion that flexibility is a key capability in allowing adaptation to the manipulation of EC level. The next made predictions about how EC training might affect those sub types, the crucial prediction being that high creative flexibility would bolster gains and ameliorate losses brought about by EC improvements. Finally, the accuracy of the predictions was tested using the data from the quantitative study. With the caveat that findings must, due to the small numbers involved, be interpreted cautiously (and suspending expectations that they will be fully supported by statistical tools), predictions were accurate: the high flexibility group saw the greatest gains in creative fluency and the smallest losses in creative originality while the low flexibility group saw the opposite. These findings give further weight to the suggestion in earlier chapters that the creativity of individuals with low flexibility is likely to be particularly adversely affected by EC gains. To sum up, this triangulation exercise provided evidence that training EC, while likely to 'succeed' in terms of improving components of EC and even some aspects of creativity, might also 'fail' in terms of carrying negative consequences for creative originality – and that this failure might be exacerbated for individuals with a specific and identifiable creative approach.

While the evidence supports the idea discussed previously, that flexibility is highly beneficial to creativity (Filippetti & Krumm, 2020; Kennett et al., 2014, 2018; Nijstad et al., 2010), it is unfortunate that the initial plan to delineate sub types according to all three aspects (flexibility, spontaneity and control) of the creative process simultaneously was not workable in practice. Characterising groups solely in terms of flexibility means the spotlight is now fully directed at a construct whose definition presents a confusing problem. Specifically, the fact that the two constructs under investigation – creativity and EC – *both* have a component referred to as 'flexibility'. To what extent are they separable?

Even within the EC literature, flexibility is defined in multiple ways. At one end is a narrow, task specific flexibility, seen in tests such as the Wisconsin card sort task (Heaton et al., 1993), in which flexibility is prompted by external cues. This is sometimes referred to as 'reactive flexibility' (Ebersbach & Hagedorn, 2011; Eslinger & Grattan, 1993). On a broader level is 'spontaneous flexibility' (Eslinger & Grattan, 1993) the flexibility deployed, for example, in semantic fluency tasks and which refers to subjects' "ability to produce a diversity of ideas and novel responses" (Fillipetti & Krumm, 2020, p. 772), a definition which sounds an awful lot like creativity (the authors themselves note a "close relationship between spontaneous flexibility and creativity"). The extent to which these different types of flexibility are dissociable or overlapping is unclear. "While the concept seems intuitive, cognitive flexibility shows itself in a broad spectrum of behaviors and lacks a unified definition" (Ionescu, 2012, p.190). Considering the multiplicity of definitions and typologies (she describes 13), Ionescu concludes that cognitive flexibility is better seen as a *property* of cognitive processes than as a specific ability. She posits that flexibility relies on two types of interaction, the first between cognitive mechanisms (attention, memory, perception etc.) and the second between cognition, sensorimotor mechanisms (since representations are multimodal; Barsalou, 2003, 2008) and context, in developmental time (p.196). How might this help us to disentangle the current findings?

Let us consider some possible explanations:

1. Cognitive flexibility is a 'property' rather than an 'ability' and as such, creative flexibility is essentially the same entity as EC flexibility. This view is given credence by the fact that both AUT and insight tasks are deployed as tests of *both* 'cognitive flexibility' and 'creativity'. By this reckoning, and assuming that flexibility training was a key ingredient of training (i.e., given flexibility's position as one of the core components of EC (Diamond, 2013; Miyake et al., 2000 and the fact that training targeted EC broadly), improved flexibility contributed both to the fluency gains and the originality losses. In this case, we would expect to see the most flexible children (as defined in their creative sub types) as seeing a stronger version of these effects i.e., greater gains in fluency and

greater loss of originality. This is not what we found, suggesting this explanation is flawed.

2. An alternative explanation says that viewing cognitive flexibility as a 'property' does not sufficiently differentiate unique features of it in different contexts – in other words, creative flexibility is *not* equivalent to EC flexibility. For example, (as per the distinctions outlined above), creative flexibility might be best described as 'spontaneous flexibility' (the 'spontaneous' reflecting a lack of external prompting to flex), tightly yoked to fluency. Eslinger and Grattan (1993) even define spontaneous flexibility as "the ready flow of ideas and answers". EC flexibility, by contrast, is predominantly the reactive type i.e., a response to specific task demands or the environmental context. In this conception, the 'flexibility' that was trained in the intervention was not advantageous to creativity because it was essentially a different skill i.e., even if it improved, it did not aid the dynamic shifting between spontaneous and controlled cognitive approaches proposed to be key to maximising creative success (see Fig. 7. 4). In this conceptualisation, the results seen are explained by the protective effect of high *creative* flexibility, which meant gains could be exploited and losses mitigated.
3. A third explanation suggests that flexibility was not the chief driver of intervention-induced change and that other components, such as inhibitory control and working memory, were mainly responsible for the changes seen in performance. We know, from pre and post-tests, that inhibitory control and working memory both improved after training. (It is unfortunate that the measure for flexibility did not work so we cannot draw conclusions about the effect of training there.) In this explanation, the balance of changes seen post training are explained by a combination of the effects of individual EC

components – for example, working memory being chiefly responsible for fluency gains (e.g., by allowing consideration of a greater volume of idea elements), while inhibitory control being more responsible for originality losses (e.g., through over-blocking potentially fruitful remote idea pathways). In this explanation, highly flexible individuals were able both to maximise the gains of working memory improvements - by utilising more focused approaches to exploit greater working memory capacity - and also to ameliorate losses - by allowing adjustment to a more spontaneous, open thinking approach, one which facilitated the emergence of distant and surprising idea elements and allowed them to be generously evaluated.

The combined explanatory power of proposals 2 and 3 accords with our overarching model, which suggests it is a higher level flexibility which is key to creativity. 'Higher level' creativity might be described as switching between strategies of which tasks to use, in contrast with the 'lower level' flexibility of switching between tasks. This higher type of flexibility was not specifically trained through the intervention, whose games and activities were focused more on the lower-level flexibility of switching between tasks, rules, games, partners and so on; the training neither required nor specifically encouraged switching between different modes of thinking.

This conceptualisation of flexibility is consistent with other studies of creativity in children. For example, Krumm and colleagues used structural equation modelling to look at the relationship between creativity, EC, and intelligence in 8-13year olds. The terminology is somewhat confusing because they define shifting as 'spontaneous cognitive flexibility' (i.e., high level flexibility) but include it within their EF measures (in which flexibility is typically operationalised as lower level). That problem notwithstanding, their findings show that this shifting factor was the main predictor of creativity (Krumm et al., 2018). In a more real-world setting, albeit with adults, this depiction also aligns with portrayals of creative individuals based on biographical studies, such as those by Csikszentmihalyi (2014). He suggests that the key feature of creative individuals is not any single trait but rather their tremendous flexibility, which allows them to shift between introversion and extroversion, sensitivity and coldness, arrogance, and humility.

The emergence of such an ability is likely to be somewhat delicate, depending as it does on a series of complex interactions between different cognitive processes as well as between cognition, sensorimotor mechanisms, and context, making it unsurprising if some struggle to fully achieve it. And perhaps it is often not even 'mission critical'. Ionescu (2017) suggests we might consider the opposite of flexibility not as 'inflexibility' but rather as 'stability'. In other words, for many tasks and in many contexts, the best strategy might well be a 'business as usual' one, stable and predictable. Perhaps the special effort of flexibility that is required to step off the familiar path and venture into the unknown is what makes creatives creative.

There is another question to address, regarding findings on originality. Given our general predictions about flexibility and since "flexibility in creativity has been related to originality of ideas" (Kennett et al., 2018), we would expect greater flexibility to be associated with better scores for originality. However, the data showed that the trend for all three groups was similar: there were modest gains in originality immediately post intervention but these were followed by greater losses by follow up, such that all three groups had lower originality scores at the end than the start. The flexibility of the highly flexible group was insufficient to fully repel these negative effects on originality. However, the losses for the highly flexible group were less than for the other groups – their mean originality score was 1.05 at the start, rising to 1.18, then falling again to 0.95, a pattern closer to stasis than the clear decline seen in lower flexibility groups. A plausible interpretation is that the improvements brought about as a result of training were such that gains in some aspects of EC e.g., working memory, proposed to improve fluency, were more than offset by increases in other aspects, e.g., inhibitory control, which restricted exploration of remoter ideational pathways and put stricter kerbs on candidate ideas. Greater flexibility allowed exploitation of the benefits of the former, but it was not sufficiently powerful to resist the force of the latter. Originality, as we have seen before, is particularly fragile. It should also be considered, due to the absence of a 'business as usual' control, that there are other possibilities, such as an effect of development or task repetition, which cannot be ruled out.

There remain inconsistencies. If we return for a moment to the essential intervention findings - that working memory and inhibitory control both improved after training, and that alongside these improvements, creative fluency increased and originality decreased - there are reasonable questions we might raise. For example, does the fact that ideas were of poorer quality not suggest that evaluation, generally seen as a deliberate, controlled process (Beaty et al., 2014, 2015; Benedek et al., 2019) was weaker? How do we square this with the findings of increased inhibitory control? Perhaps inhibitory control acts earlier in the creative cycle, such that good, surprising candidate ideas do not have the opportunity to 'pop up' spontaneously in the first place. Or perhaps the fact that the task was no longer novel meant that children were giving less in terms of effort and imagination. 'Openness to experience', one of the *Big Five* personality factors (McCrae & Costa, 1987) and manifested in novelty, has been strongly associated with creativity in many studies (DeYoung et al., 2005; Dollinger et al., 2004; Prabhu et al., 2008; Runco, 2014). Practice had reduced novelty while giving children an understanding of how to succeed at the task through the application of proximate, prosaic generation strategies. These allowed them to optimise for fluency, but not originality.

There are other current theories regarding the relationship between EC and creativity which our data did not support – for example, the popular view that inhibitory control benefits creativity by blocking obvious or previous ideas (Benedek et al., 2012; Camarda et al., 2018; Cassotti et al., 2016). "The ability to inhibit common and dominant paths of solutions to a problem seems to be a critical process for generating creative ideas" (Camarda et al., 2018). In our study, the evidence pointed in the opposite direction; greater inhibition was associated with a pattern of higher fluency and lower originality – an increase, in other words, of just those 'common and dominant' ideas that others suggest inhibitory control is there to outlaw.

The role of working memory in creativity is less controversial, it generally being seen as beneficial (De Dreu et al., 2012; Korovkin et al., 2018; Remoli & Santos, 2017) but even here our data raise questions. For example, if we argue, as we have, that improvements in working memory facilitated consideration of a wider palate of idea elements which contributed to fluency gains, why did these not include the sort of further-reaching associations which are key to originality? Why did the benefit extend only to fluency and not to originality? Again, the best answer we can summon involves an appeal to the particular fragility of originality, making it particularly susceptible to other perturbations and perhaps particularly stimulated by task novelty. It might be that excessive inhibition (in its broadest conception) contributed to a failure to 'let go and explore widely', in favour of a close, familiar, goal-directed approach exploring a known problem space. Simply put, most children chose the safer path.

To sum up, the findings broadly supported our hypothesis that greater flexibility promotes creativity, through allowing the ideational reins to be loosened or tightened according to need.

This ability to shift between approaches means that different facets of creativity – originality and value, quality, and quantity – can be maximised. We have proposed that the mechanisms by which this occurs rely on interactions of creative flexibility with the core components of EC, for example exploiting working memory to increase fluency. We also suggested that increased inhibitory control contributed to a loss of originality such that even the most highly flexible children could not completely resist. These theories need further research to uncover the relative contribution of the different factors and the mechanisms by which they operate. For example, one way this might be tackled is, following from Radel and colleagues (2015), by taxing inhibitory control immediately prior to a creativity task in which instructions are also manipulated (to compare 'Be fluent' with 'Be creative'; Beaty & Silvia, 2012; Chen et al., 2005) and analysing differences in process and outcomes.

Limitations

Some of the broad limitations of triangulation have inevitably been touched upon – inevitably, given triangulation has many limits. The hope is that the gains in knowledge and insight outweigh the compromises. In this study it was a particular frustration to be unable to draw upon familiar statistical tools to substantiate the significance and magnitude of findings, though the numbers involved would make such an attempt meaningless. This knowledge does not necessarily quell the disquiet.

At a more micro level were issues with coding, scoring, and devising tools to transform qualitative words into quantitative numbers. For example, with regard to flexibility, one limitation in the creation of individual scores was the conflation of scores which arose from reactive flexibility (e.g., points for numbers of categories of response) with those of spontaneous flexibility (e.g., points for multiple diverse strategies for getting unstuck). Coupled with this was the limitation, already discussed, that the measure of 'EC flexibility' did not work, a shortcoming that limited the conclusions that could be drawn about the nature of this construct.

Another scoring compromise came from giving points according to the provenance of responses, since there were often multiple sources and it was not always obvious which was predominant. The differentiation of EC and non-EC relevant processes also meant simplifying responses which were complex and multifaceted into binaries.

Clearly, the delineation of creative sub types posed its own challenges. Whether this was a limitation as such, or an inherent difficulty is debatable – but certainly the objective of defining types according to an axis from most EC ('Control') to least EC ('Spontaneous') was not realised. More profoundly, questions arose about the benefit of characterising groups in terms of a process which other evidence has suggested might be highly individual. What does or does not constitute a suitable group number? Whose qualities must be moulded to fit? Which elements should be prioritised? The end goal – to understand the mechanisms involved in children's creativity in order to improve it – must always be kept in mind.

Reflection on the process and findings of triangulation again raises the question of whether we learn more by bringing these data together than keeping them separate (Hesse-Biber & Johnson, 2015; Noble & Heale, 2019; Tashakorri & Teddlie, 2009). The question presents something of a bind: there are undoubtedly difficulties, compromises and shortcomings involved in drawing conclusions derived from combining diverse data sets. But if there exist meticulously collected quantitative and qualitative data focused on the same research questions and gleaned from the same population, surely it would be a greater failing not to try? The paradox of triangulation is that it appears to hold the greatest potential for meaningful, thoroughgoing findings, but possesses the least clearly defined tools for establishing that meaningfulness (Wolf, 2010).

Perhaps, taking a broader view, we should remember that triangulation is "not aimed merely at validation but at deepening and widening one's understanding" (Olsen, 2014, p. 103) and that it is particularly well suited to support interdisciplinary research. The suggestion of Runco (2008) that creativity is unlikely ever to be understood using only traditional scientific approaches and given the importance of creativity to so many different fields, the trials of triangulation are surely worth the effort.

Conclusions and next steps

This chapter brought together the quantitative intervention data which told of change in performance over time and the qualitative data which gave information about children's individual approaches to the creative process. The aim was to see if understanding the role of executive control in children's creativity could allow accurate predictions to be made about individual effects of EC training on creative outcomes. Within the limits outlined, the answer was a tentative 'yes'. Evidence from combining the data supported the hypothesis (derived from our model) that high flexibility would act as a 'protective buffer' for creativity, enhancing gains and ameliorating losses. The research also raised important questions regarding the nature of flexibility and the degree to which it is a specific ability or a more general process.

In the next chapter, we will bring all the findings together. The goal will be to assess all we have learned about the role that EC plays in children's creativity, with the ultimate aim of addressing how best to advance this most important component of '21st century skills.'

Chapter 8. Discussion. Bringing the kaleidoscope into focus

Introduction

This final chapter will synthesise findings and situate them in the context of education and the ‘21st century skills’ agenda. Can what we have learnt help to define and realise best practice in achieving 21st century skills, particularly in a turbulent world? This thesis is being produced in the second year of the Covid-19 pandemic. The events of the pandemic have been so seismic that they have pushed even traditionalists to review the ‘business as usual’ approach to education; what constitutes ‘usual’ has been and continues to be redefined, as learning has moved online and teachers, students and parents have had to bend and flex to new rules. Where do creativity and EC sit in this new world? Is it possible to promote both, and if so, how? We will finally discuss some future research directions relevant both to aiding a better understanding of creativity and, our goal, maximising the chances of improving it.

Summary of findings

Research questions revisited

The main goal of this thesis has been to understand the role that executive control plays in children’s creativity. The specific research questions raised at the outset are revisited below and concise answers given. Each will be considered in more detail, and in wider context, in the sections that follow.

To what extent are there individual differences in the role EC plays?

Evidence from both qualitative studies (Chapters 3 and 6) pointed to considerable variation in children’s deployment of EC in their creativity, both across the 12 children involved in a free-ranging creative work and the 16 children who completed the AUT. Narrative reports indicated that while some drew primarily upon a highly focused, EC dependent approach, others were primarily reliant on ideas arising spontaneously, away from the attentional spotlight. The degree to which children modulated from one sort of approach to another also varied widely between children, and for some children, also varied according to domain, level of constraint or other factors.

At a broader level, there were also similarities. All children deployed EC to some extent in their completion of creative activities: they all attended to the task in hand, sometimes over long periods, they remained seated, they behaved appropriately, listening to and meeting instructions. Children also showed similarities in generally ascribing a greater role for EC involvement in the evaluation of ideas than in their generation. While there were wide differences in generative approaches - for some children, generation was primarily strategic and tactical (i.e., EC driven), for others it was highly spontaneous (i.e., EC independent) - there was more similarity in an evocation of EC in evaluative approaches. For example, Dave (age 6) systematically applied logic to decide which ideas merited inclusion, “Do pigs live in sandy places? No. Would a witch want to be in a desert to do a spell? I don’t think so”. This finding, of a greater role for EC in evaluation than generation, is in line with previous research (Beaty et al., 2012, 2014; Ellamil et al., 2012; Ivancovsky et al., 2019; Mayseless et al., 2015a). The demonstration of the variety of EC deployment in generation has been less studied and presents as a more novel finding.

Does inhibitory control have a detrimental effect on children’s creativity?

Different sources and types of evidence shed light on this question. The first, indirect evidence came from findings which showed that improvements in IC (lab measures) were not accompanied by creativity improvements. This disconnect was first seen in the cross-sectional study of Chapter 2, which found that while EC measures increased reasonably steadily with age, most creativity measures did not. Only AUT originality scores bucked this general trend. Chapter 4's triangulation study provided evidence of negative correlations between 'control' (as evaluated qualitatively) and creative output in terms of both fluency and originality (as measured quantitatively). The results of the training study (Chapter 5) bolstered this finding, showing that trained improvements in inhibitory control co-occurred with losses in creative originality. The picture was not straightforward, however, since there were simultaneous gains in creative fluency. These findings might be explained by opposing effects of inhibitory control on different dimensions of creativity. Alternatively, they could be explained by opposing effects of different EC factors. For example, improved creative fluency might have been facilitated by improvements in working memory (which also improved after training) or greater flexibility (more speculatively, since its improvement was not measured), rather than the impact of inhibitory control. Finally, evidence from the qualitative study of the AUT (Chapter 6) showed the variety of possible negative effects brought about by inhibition, including a loss of good ideas through overly strict evaluation, functional fixedness, and excessive focus leading to creative block. More work is needed for confidence regarding the mechanisms involved, but the balance of evidence suggests that inhibitory control can have a detrimental effect on creativity, a finding supported by some previous research (Radel et al., 2015; Reverberi et al., 2005; White & Shah, 2006) but refuted by others (Benedek et al., 2014a; Edl et al., 2014; Groborz & Necka, 2003). The apparently contradictory findings reported in the literature are not necessarily actually contradictory; as we have discussed, inhibitory control itself has many dimensions (Benedek et al., 2012; Cheng et al., 2016; Friedman & Miyake, 2004; Nigg, 2017) and it is possible, as suggested in the introduction that inhibition "can serve to enhance creative thinking in some instances while impairing it in others" (Storm & Patel, 2014, p. 1597).

To return to the research question here, the current findings suggest a negative role for inhibitory control in creativity, with little support for a positive one. Moreover, given the broad recognition – even the accepted wisdom - that EC improvements are unassailably a 'good thing' (Diamond 2012, 2013; Diamond & Lee, 2011; Diamond & Ling, 2016; Huizinga et al., 2006; Peters, 2020), it is especially important to question this assumption and present evidence of previously unconsidered negative side effects.

What is the effect of training EC on children's creativity?

The EC training intervention (Chapter 5) produced findings which were somewhat hard to interpret but considering all the possible explanations for the improvements seen in EC measures, the most reasonable is that the intervention training worked. The level of improvements to EC were considerably greater than would be expected by development over the test period of the study, both in terms of evidence from the wider literature and change seen in the cross-sectional study in Chapter 2. Ambiguities arose firstly because results were largely undifferentiated by group (training vs active control) – that is, the control condition showed improvements too, and secondly because the transfer effect to creativity was mixed. The likelihood, given the nature of the active control and the inevitability of implicating EC in learning and playing several, new games of increasing difficulty, is that it too successfully trained EC. With hindsight, efforts to isolate the 'active ingredient' of training could have been improved. The lack of a 'business as usual' control made it difficult to confidently differentiate training from other effects (practice, development). The quantity of output (i.e., fluency) showed increases alongside EC gains (as measured by tests of WM and IC) while quality (i.e., originality) showed decreases, an outcome seen in both verbal (AUT) and figural (TTCT) domains.

Given the novelty of this study design (i.e., the approach of training EC to explore the effect of EC on creativity), there is little potential for direct comparison with the wider literature – though the mixed nature of the findings endorses an established idea that, given that neither EC nor creativity are monolithic, their relationship is likely to be complex (Basadur et al., 1995; Beaty et al., 2016; Chrysikou, 2014, 2019; Pinho et al., 2016; Sowden et al., 2015a; Vartanian et al., 2019, 2020). Here, it seems likely that some components contributed positively and some negatively. For example, as suggested above, WM and flexibility might have contributed positively to fluency while inhibitory control might have contributed negatively to originality. (Benedek et al., 2014a; Radel et al., 2015; Zabelina et al., 2019). The headline of these findings, however, is worth emphasising: the overall effect of EC training was to make children produce more, worse ideas. Given the primacy of originality in nearly all conceptions of creativity (Abraham, 2018; Dietrich & Haider, 2015; Runco & Jaeger, 2012), this is essentially saying that EC training made children less creative. Given that most schools are engaged much of the time in practices which demand EC (paying attention, being still and quiet, listening to and carrying out instructions, controlling behaviour etc.) this finding compels further investigation.

Does the effect of training differ between individuals?

We draw on evidence from Chapter 7 to suggest that the answer is yes, though with the caveat that the level of individual variation, particularly in change of originality scores, was very high. Consideration of the differential effect of training involved categorising children according to their level of flexibility, which was seen as the key feature in allowing children to follow more spontaneous or more controlled pathways, according to internally or externally driven cues and constraints. Findings showed that although the general direction of outcomes after training was broadly similar for all sub-groups (i.e., fluency increased and originality decreased), individuals with the highest level of creative flexibility saw the greatest gains in fluency and the smallest losses in originality. We suggest that the explanation lies in the more flexible children being better able to exploit gains in WM to enhance fluency while also evading the loss of originality brought about by excessive control by switching to more spontaneous approaches.

Additional findings of note

Originality is fragile

Producing good ideas is an unpredictable and uncertain process. This notion, which chimes with common sense (that is, the familiar difficulty of having to come up with a good idea on demand) is probably a key determinant in what makes creativity both precious and opaque (Dietrich, 2015; Reiter-Palmon & Schoenbeck, 2020; Runco, 2014). It is nonetheless important to scientifically verify it (after all, the world, despite appearances, is not flat) as well as to assess and quantify the extent of its unpredictably. Returning to data from the EC training study, Figure 8.1 below shows originality scores for individual children at the three test time points. The individuals, the context, the instruction, the setting, the task, even the time of day, the type of paper, the desk, the pencil, the testing team, all remained the same; the only deliberate difference was the stimulus – i.e., whether children were considering a plastic bottle, a pencil or a sock. Even taking a pessimistic view on alternate-form reliability (e.g., Barbot and colleagues (2016) suggest a range of .30 to .40; see also Barbot et al., 2019a; Reiter-Palmon et al., 2019), the measures still appear chaotic, suggesting the contribution of multiple small, idiosyncratic, unmeasured (and possibly unmeasurable) effects to creative originality. This presents an enormous research challenge.

It need not, however, mean it is hopeless to try and improve it. As we will see in the following sections, there is a considerable body of evidence which shows that originality can be improved

(Fasko, 2001; Michalko, 2001; Root-Bernstein & Root-Bernstein, 1999; Rose & Lin, 1984; Runco, 2014; Scott et al., 2004; Sowden et al., 2015b; Zabelina & Robinson, 2010b). By

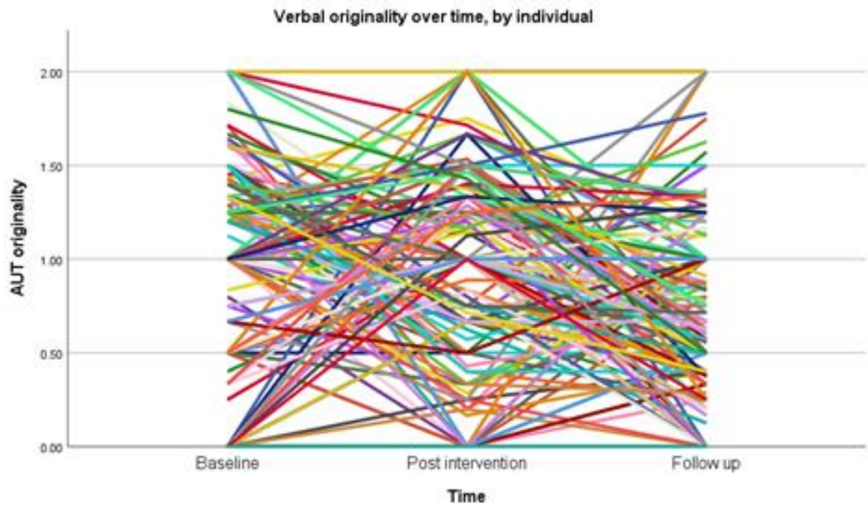


Fig. 8. 1 Originality shows a very high level of variability at different times. Pearson's r between baseline and post: .07 (p=.367) and between post and follow up: .16 (p=.048), n=156.

analogy, even the greatest professional golfer does not expect to achieve a hole in one on every hole, since there are so many variables which individually and minutely contribute to success. However, the odds of an amateur golfer making a hole in one are 12,500 to 1, while for a professional, the rate is 2,500 to 1 (US Hole in One website, 2020).

Children appear able to report on their creative processes

The qualitative methods used, being largely exploratory, were necessarily somewhat tentative. Although other studies have used some aspects of the current methods, such as stimulated recall (Järvelä & Volet, 2004; Lyle, 2003; Meier & Vogt, 2015; Morgan et al., 2007; Vandevelde et al., 2015) and others have conducted similar research in adults (Gilhooly et al., 2007; Pringle & Sowden, 2017a), this research was novel in using children's verbal reports as probes to illuminate cognitive mechanisms. We will not restate the vigorous debate which still shrouds such approaches (Braboszcz, 2012; Fazelpour & Thompson, 2015; Nisbett & Wilson, 1977;

Petitmengin, 2006; Petitmengin & Lachaux, 2013; Petitmengin et al., 2013) but will say that the experience of conducting such research and the creation of the '7Cs' validity checklist, leave me with optimism about the potential of such approaches. If conducted with care and attention to detail in the nature and content of questions (as counselled by Petitmengin and colleagues; 2013), these methods could be productively used in the future to document acts of everyday creativity. The importance of this would be allowing spontaneous aspects of creativity to be studied – and in real world environments (Amabile, 2017; Kaufman & Beghetto, 2009; Runco, 2014). As several researchers have pointed out, one of the most obdurate problems of researching creativity is catching people 'in the act' of creativity – and gaining insight into their mental processes as they are at it (Dietrich, 2015; Sowden et al., 2020). According to the editorial in the first issue of Neuroimage ever dedicated solely to creativity (Neuroimage, Special Issue on the Neuroscience of Creativity, 2021), it is particularly important in the early stages of a field to highlight "promising research directions toward stronger coalescence around methods and questions that have potential to catalyse basic understanding of how creativity occurs in the brain" (Saggar et al., 2021). Put simply, for a research area still in its embryonic stage, all potentially useful new tools should be generously considered.

Methodological issues relevant for future research

Flexibility could be key – but the construct needs clearer definition

In Chapter 7, flexibility, as assessed by a scoring system which combined qualitative and quantitative components, was shown to relate positively to creativity, with the most flexible children performing the best in terms of both fluency and originality after training. Flexibility (also conceptualised as 'balance' processes) also emerged as one of the three key themes in the first qualitative study in Chapter 3. For some children, the flexibility to shift thinking approach was deliberate (e.g., Betty, “I realise I’m concentrating too hard and… then I sit back and then I relax and then after [the idea] comes to me”). For some, it was related to the stage of the creative process (e.g., Roxy, “If I was thinking of a subject immediately like loads of ideas come to my mind so then I try and like ‘Caaaaalm down’ and just find one that really captures me”). For others, the balance seemed to shift spontaneously, with outcomes sometimes favouring an open spontaneous approach, and sometimes a more focused one (e.g., Lexy, “When my cat walked past I remembered and then I thought cheetah’s in the cat family so I wanted to draw that… [a few minutes later]…If I heard the beeping noise it would remind me of a car and I might start drawing a car on water…I didn’t do it [get distracted] because I reminded myself I was doing that”).

These examples describe macro level shifts in thinking approach, as illustrated in our model of creativity in Figure 8.2, suggestive of the network level switching described by other researchers. In Gabora’s honing theory (Gabora, 2011, 2016; Scotney et al., 2020) creativity arises through the process of shifting between associative and analytic thought processes in response to task demands e.g., emphasising a shift “from an analytic to an associative type of thought when stuck in a rut and from an associative to an analytic process following insight” (Sowden et al., 2015a, p.46). Other creativity researchers have suggested that what is unique in the creative process is the unusual coupling between the default mode network and the central executive network, which normally work in opposition - that is, a stimulus-independent system has been yoked to attentional control. (Beaty et al., 2015, 2016; Chrysikou, 2019; Chrysikou et al., 2014; Vartanian et al., 2020).

There are still many open questions, for example concerning the mechanisms which might govern a change in coupling, whether it is spontaneous or under top-down control, the timescale, speed, and frequency of switches and much else (Barr et al., 2017; Basadur et al., 2000; Ivancovsky et al., 2018; Menon & Uddin, 2010; Pinho et al., 2016; Sowden et al., 2015a; Vartanian, 2009).

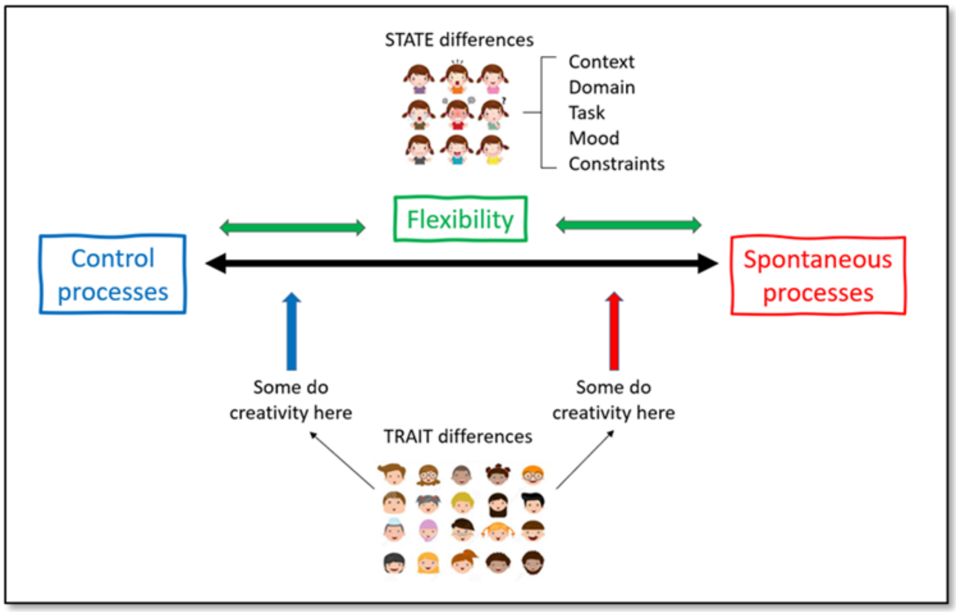


Fig. 8. 2 Model highlighting flexibility as key component of the creative process, allowing the creative process to draw upon more controlled or more spontaneous processes

In our studies, flexibility also appeared to operate at other levels. As well as the high level illustrated above, there were examples of flexibility at a low level, such as in seeing a shape in a new way or opening up ideas in a new category (e.g., Alex, “like in this picture I was about to rub out the roof but then… I thought that it would be cool if it was like this side was haunted and this side was like really cool like good” or Dave, “if I moved that piece around and I put it there that could be a leg and if I put four more it would be like the legs of an animal and that would make sense”). To what extent are these different ‘flexibilities’ the same thing? And when researchers argue that flexibility is beneficial to creativity (Filippetti & Krumm, 2020; Kennett et al., 2018; Nijstad et al., 2010) what level of flexibility are they referring to? As Ionescu has pointed out, the concept of flexibility seems intuitive but has no single agreed definition and multiple operationalisations conflate externally driven and internally driven processes and many levels (Ionescu, 2012, 2017).

These conceptual and practical problems with the construct of flexibility were well illustrated in our studies. Concerning the multiple levels at which flexibility operates, we saw the difficulty of comparing across different levels of description. For example, in Chapter 7, we calculated flexibility scores according to both a narrow definition of flexibility (e.g., category switching in ideation) and a broader one (e.g., description of different types of concentration). But are these in fact aspects of different skills? A second problem was a practical one concerning quantifying switching ability; there was only one explicit test for switching (i.e., the EC conceptualisation of flexibility) which used the Complex Flanker to cue children to switch between different rule sets. This type of switching flexibility differs from that described in the creativity context in being externally rather than internally cued, or 'reactive' rather than 'spontaneous', in Ionescu's (2012, 2017) vernacular. The bigger practical problem was that the test did not work, probably because there were too few trials to robustly measure the difference between switch and non-switch response times – so we were unable to assess whether this narrow, externally driven EC flexibility related to our broader internally driven creativity flexibility. This brings us to the third and biggest problem with the construct of flexibility – namely, that it is positioned as a central feature of both EC and creativity, the two constructs that we are seeking to relate.

If we return to Diamond's conceptualisation of EC presented in Chapter 1 (shown here in Fig. 8.3) we see that she includes flexibility as part of the constellation of EC skills – and goes so far as to characterise it as 'thinking outside the box', a phrase normally preserved for creative thinking. Clearly there is a problem here, an acute one when we are interested in the relationship between EC and creativity: we cannot use flexibility to simultaneously represent both constructs

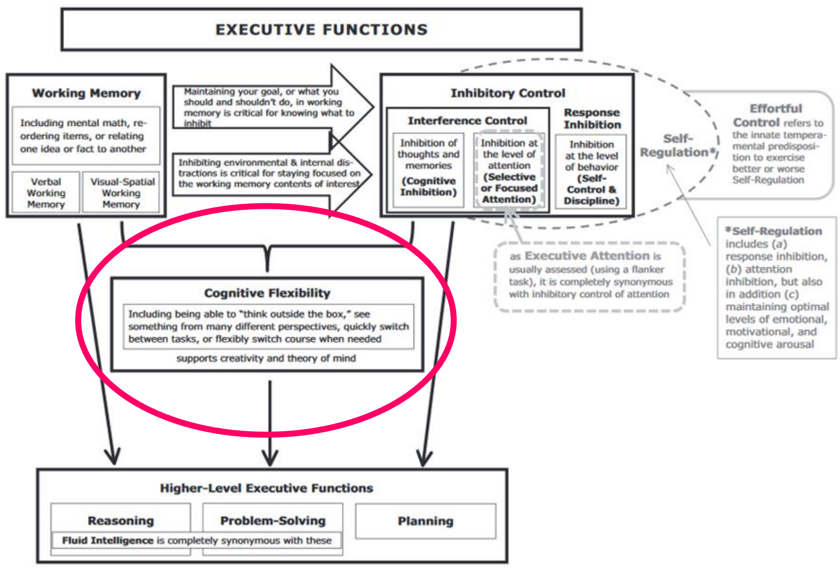


Fig. 8. 3 Diamond, 2013. Outline model of executive functions (EC), highlighting a definition of ‘cognitive flexibility’ which includes ‘being able to think outside the box’, a description which overlaps with creativity

(Benedek et al., 2014a). Sometimes, in trying to assess relationships between constructs, researchers employ tests which are so overlapping they only muddy the water further. Let us consider an illustration of the problem. Krumm and colleagues (2018), report on a study which attempts to elucidate the relationship between creativity, executive functions and ‘fluid’ and ‘crystallised’ intelligence (also rather abstruse constructs). In doing so, they use three tests for the switching dimension of executive control. The first is a standard card sort task. The second is a ‘semantic fluency’ task which is often also used as a divergent thinking task (Friesen et al., 2015) i.e., an important aspect of creativity. The third is the ‘five-point test’ (Regard et al., 1982), a measure of visual fluency, whose features closely intersect with the sort of problem-solving tasks used to test convergent thinking (Danek et al., 2016), i.e., another, different aspect of creativity. We can hardly expect to decipher relationships between constructs when the tasks being used to represent them are not separable (Dietrich, 2015).

New approaches are needed to create order from this muddle, and if we believe that flexibility is important for creativity, we need to try - not least to understand a possibly fruitful means to improve creativity. One approach, counselled by Ionescu (2012), is to clearly distinguish between ‘reactive’ and ‘spontaneous’ flexibility, the former being top down, EC driven and the latter – the process of changing tack without needing to be told - more a feature of creativity and arising without planning. This separation is based on the important distinction between someone successfully reacting to a decreed rule change and their instinctively identifying the need to switch. Failure in each case looks very different: failure of ‘reactive flexibility’ is perseveration, i.e., sticking with an old rule when a new one should be observed. This sort of paralysis has been well documented, particularly in young children (Kirkham & Diamond, 2003; Morton & Munakata, 2002) – and is rightly seen as a negative. Failure of ‘spontaneous flexibility’ is different. It might in fact not be positioned as failure, but rather as stability (Ionescu, 2017): new avenues have not been explored, risks have not been taken, but less has been lost – there is a kind of safety, as opposed to simple failure. There might even be occasions in which the most adaptive strategy is to stick with the known, even at the cost of original thinking; it is why we must generally be given a push to think ‘outside the box’. Our usual focus is inside it. In the context of school and doing well on stable, standardised tests, perhaps this is often precisely what is required: to keep delivering the familiar. It seems possible that the children in our study, who with greater EC, produced a larger quantity of more predictable responses, were doing exactly that – producing more of the same, the expected. Simply, originality conflicts with stability. And that is why flexibility emerged as a key factor in helping children move away from the stable, rehearsed, obvious responses, to produce something new.

For a thorough cognitive account, we need to be more specific about what mechanisms might underpin this ‘instinctive’ need to change strategy (i.e., the kind of flexibility we are suggesting is key to creativity). Speculatively, there are two possible suggestions for what such an ‘instinct’ might comprise. The first is some kind of monitoring mechanism which compares current output against future goals (the sort of error detection often attributed to anterior cingulate cortex; Botvinick et al., 1999, 2004). A child observes their output and, weighed against some internalised metric, does not consider it creative enough and this triggers a change in behaviour or strategy which results in a more creative outcome. By way of illustration, Imagination Creation (a child from the first qualitative study) first said, “I was going to do broccoli…” (output is weighed, result deemed inadequate, strategy altered), then continued, “… but if I did corn that could turn into popcorn… so it’s kind of like a real shape shift”.

The second would be more akin to the sort of reinforcement learning which evaluates trade-offs (in terms of rewards) between exploitation and exploration and which relies on interactions between the striatum and the PFC (Crone & Molen, 2004; Crone & Ridderinkhof, 2011; van den Bos et al., 2012). Exploitation maximises rewards from known approaches, but at the risk of missing out on other potentially greater rewards, while exploration is a riskier approach, giving up guaranteed rewards in favour of acquiring new knowledge. This involves exploring what else might be on offer – the rewards of novelty seeking outweighing the scant reward of being bored. The balance of exploitation to exploration could be conceived as a trait difference between children, or a state difference over time on task (as seen, for example, in the serial order effect, when fluency yields to originality – or in these terms, exploitation gradually shifts to exploration). Kitty (another child from the first qualitative study) seems to be speaking from the perspective of someone who can regretfully see, post hoc, that they failed to shift from exploitation to exploration when, reviewing her finished picture, she said, “I could have changed the colour of the sea and the mountains the sun and the moon I could have changed the gas in the clouds… but I didn’t… I just wanted to draw a creative picture but I don’t think I did one so I think I’ve just done a normal picture.” Both monitoring and reinforcement learning would proffer mechanisms that, intuitively and neurobiologically, might crystallise the idea of flexibility as ‘instinctual’.

Another approach to decongest the flexibility blockage is to get very specific about tests. For example, Kenett and colleagues (2018), defining flexibility as “the ability to create and use new mental categories and concepts to reorganise experience” (p. 867) have developed new computational models to test the rigour of semantic networks (see Figure 8.4 below). They point out that, to date, the role of flexibility in creativity has only been measured indirectly and instead propose a new measure based on how robust semantic memory networks are to attack, with the presumption that more flexibility will equate to greater robustness as individuals find alternative pathways.

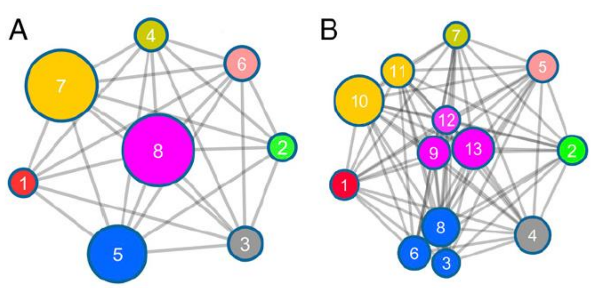


Fig. 8. 4 Kenett et al.’s illustration of the semantic networks of low (A) and high (B) semantic creatives, based on tests of semantic associates in 140 adult participants. Components are sized according to their number of nodes and numbered according to their disconnection order from the most highly connected component. More creative individuals, characterised by a greater number of associations of variable distance, have greater flexibility.

This concept of using stress-testing to distinguish more flexible from more rigid individuals, could be used in other, non-computational approaches which focus on dynamic or combined rather than static measures. For example, exploiting the well-established ‘be creative’ and ‘be fluent’ effects (Forthmann et al., 2016; Nusbaum et al., 2014), individuals could be asked to complete DT tests first with the instruction to ‘be creative’ and scoring only for originality, then with the instruction to ‘be fluent’ and scoring only for fluency. While the most flexible individuals might not perform the best on either test alone, they should be least impaired by the need to adapt approach, which would be shown in the smallest difference scores. Additional tests of regular EC switching (e.g., to include a card sort task) would aid disambiguation of flexibility types.

Mixed methods are painful but necessary

Some of the most important findings of this thesis came into focus only through the mixed methods lens. The evidence that children can arrive at identical scores in DT tests through applying very different approaches is a good example of the power of combining methods, as well as a rebuke to the power of DT tests alone ever to reveal mechanisms. Let us remember that the tests used to assess ‘creativity’ are those which have been the backbone of creativity research for the last 75 years (Guilford, 1966; Kim, 2006; Reiter-Palmon et al., 2019; Torrance 1966, 1972, 1974) and which, despite 75 matched years of criticism, retain dominance today. I am far from the first to critique them (Dietrich, 2015; Plucker et al., 2014; Plucker & Runco, 1998; Silvia et al., 2008; Simonton, 2003). However, I think the nature of my critique is new. These tests are purported to measure, most modestly, people’s ability to think divergently and, more commonly, their ability to actually be creative. But the evidence presented here demonstrates that individuals are engaging greatly differing processes when they are completing these tests.

This raises questions beyond practical considerations of scoring methods and reliability; rather, they bring into question *what* these tests are actually measuring. Certainly, the scores produced can tell us little or nothing about process.

The combination of methods was also pivotal to the finding that flexibility might act as an important protective buffer in creativity, and, further, in characterising and specifying what flexibility actually comprises in the act of creating. These two examples illustrate an important and sometimes overlooked aspect of mixed methods: they are as useful for generating new research questions as for directly producing answers (Johnson et al., 2007).

The need for mixed methods relates to a bigger, lingering problem of creativity research: that creativity is not a cognitive process, so much as an activity which involves the iterative use of *multiple* cognitive processes, as well as interaction with external objects and representational formats, over an extended period of time. This is very different from the bounded mechanisms operating over milliseconds which typically describe cognitive processes. Quantitative approaches measuring creative outputs necessarily compress this extended interactive multi-mechanism activity into the rating of a single ‘creative product’. Qualitative approaches offer promise in informing the stages, the connections between them and the changing approaches to new iterations which comprise creative activity as a whole.

Mixed methods undoubtedly present challenges. First and most simply, there is the extra work of gaining expertise in both quantitative and qualitative methodologies. Second there is the daunting task of traversing an epistemological no-man’s land, with snipers on all sides, picking off weaknesses in validity, robustness, generalisability, and replicability on one side and shortcomings in richness, meaning, detail and depth on the other. Third, and for me most difficult of all, is the practical task of bringing data sets together. Here the difficulties are caused by the fact that every triangulation exercise is unique, that numbers in qualitative studies will always be too small to offer a conventional level of statistical certainty and that the tools for testing validity and reliability are less well developed in what is still a new and evolving research paradigm (Hesse-Biber, 2015; Morgan, 2014; Tashakkori & Creswell, 2007). At the same time, it is almost impossible to think of a complex question which can be satisfactorily answered with only one tool. The level of our understanding of how creativity happens in the brain is still rudimentary; such a stage of excavation demands an assorted toolkit.

The issue is particularly acute for the cognitive psychology of creativity. While social psychology has successfully evolved from studying creativity primarily through documenting eminence (Beghetto & Kaufman, 2007; Kaufman & Beghetto, 2009; Simonton, 2010a) to understanding the traits and tendencies (e.g., tolerance of ambiguity, openness to experience) which facilitate everyday creativity in 'normal people' (Amabile & Pillemer, 2012; Feist, 2010; Hornberg & Reiter-Palmon, 2017; Martindale, 1989), cognitive psychology has not. With a few exceptions (e.g., Cotter & Silvia's use of experience sampling; Cotter & Silvia, 2019; Silvia et al., 2017), it has not developed precision tools for assessing everyday creativity. The upshot is large gaps in our understanding of what goes on in people's minds as they are creating, gaps that are even greater when it comes to children. From a developmental perspective, there is a profound, ongoing question about whether children become less creative with age – or whether the child's part-formed concepts and categories make them appear more creative to adults, whose concepts – and their creative re-imaginings - are more calcified. There is scope to build novel research programmes from the ground up, for example, using verbal reports to generate new theories, which can be tested using specific and targeted quantitative experimental techniques (Abraham & Windmann, 2007; Dörfler & Stierand, 2020; Sowden et al., 2020).

Given we are ultimately interested in creativity in education, there is a pressing need for interdisciplinary approaches. “Educational outcomes need to be thought of in terms of the nested constraints that encompass the individual, classroom, school, family and society” (Thomas & Ansari, 2020, p. 5) – and we will need to get better at combining multiple, diverse tools to gain traction on multi-layered questions. The importance of “embracing complexity and giving voice through research methods and methodologies” (Meyer & Schutz, 2020, p.196) has rarely been more apparent.

Constructs of EC and creativity

This thesis has raised issues regarding the nature of the constructs under investigation and the difficulty of comparing findings from different levels of description. We have already discussed this in some detail with regard to flexibility. But the complexity and confusion there is not unique. Which version of control is the more revealing of the underlying process - a child’s performance on a computerised Flanker test or their saying they are ‘100% focused’? This is both an epistemological question for mixed methods / interdisciplinary research and a question regarding the nature and measurement of cognitive constructs.

In terms of specific findings, there are some useful illustrations. First, there were no significant correlations between EC as measured in lab tests and EC as described qualitatively. This casts doubt on either or both the ecological validity of lab tests of EC and / or the generalisability of qualitative assessments. In turn this casts doubt on the sufficiency of even multiple measures to meaningfully represent the complex construct of EC.

There was no formal evaluation of the creative products made by children outside the lab in more real-world conditions. This means we cannot statistically compare creativity in the lab with real world creativity in a similar way to EC. Nonetheless, it seems reasonable to conjecture that a similar shortcoming - a lack of coherence across different description levels and / or a lack of construct validity - is likely also a problem for creativity. Baer (2011a, 2011b) and others (Barbot et al., 2019a, 2019b; Silvia et al., 2008) have suggested that validity (predictive and discriminant) is a major problem in the study of creativity. By way of illustration, we can consider the examples in Fig. 8.5 below, which shows drawings made by two of the children in the naturalistic qualitative study. These were not formally assessed, but I think most would agree that the picture on the left is the more creative. Yet the child who did the picture on the left scored well below the mean in the AUT measures while the one on the right scored well above it. This is an anecdotal rather than a statistical report, but one that further suggests a lack of direct mapping from real world to lab creativity measures.

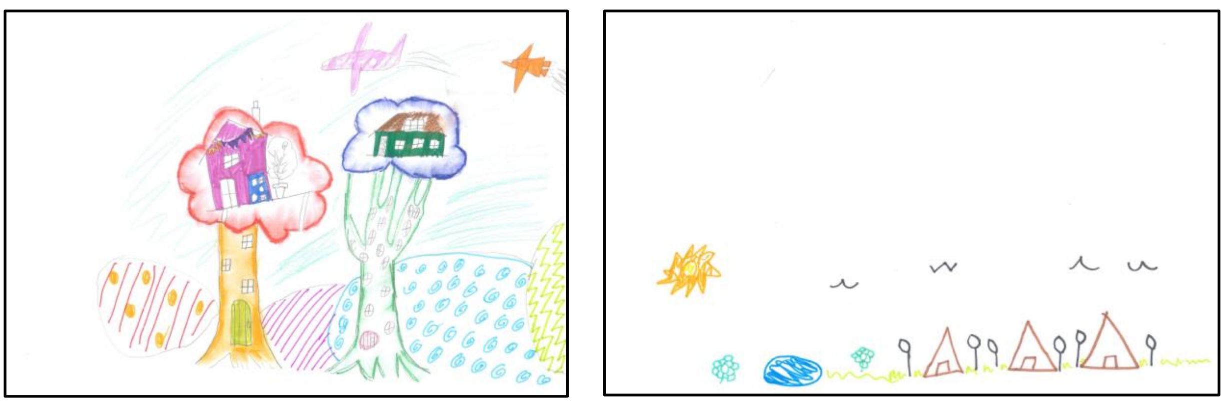


Fig. 8. 5 Examples of drawings by children with AUT fluency scores below the mean (left) and above the mean (right)

What gives? Ecological validity or statistical confidence?

Deciphering and measuring the differences between lab creativity and real-world creativity presents a pressing and difficult problem for psychology and neuroscience, one that is compounded by the many specific difficulties of studying creativity, such as time, repeatability, spontaneity, space, and movement (Abraham, 2018). For example, while many argue that creativity can happen in ways that are either deliberate or spontaneous (Dietrich, 2004) "it is clear that when we assess creativity under lab conditions, we are mainly assessing deliberate forms of creativity" (Abrahams, 2018, p.48). Several have argued for greater transparency and clarity in specifying and designing measurements in order to advance the field of creativity, since "we cannot assume that measures of creativity are interchangeable" (Reiter-Palmon & Schoenbeck, 2020, p. 290). A major challenge is presented by the fact that there are many different creative approaches. As we saw in Chapter 4 and as illustrated in Figure 8.6, the same scores can be achieved by different children operating with very different levels of EC involvement.

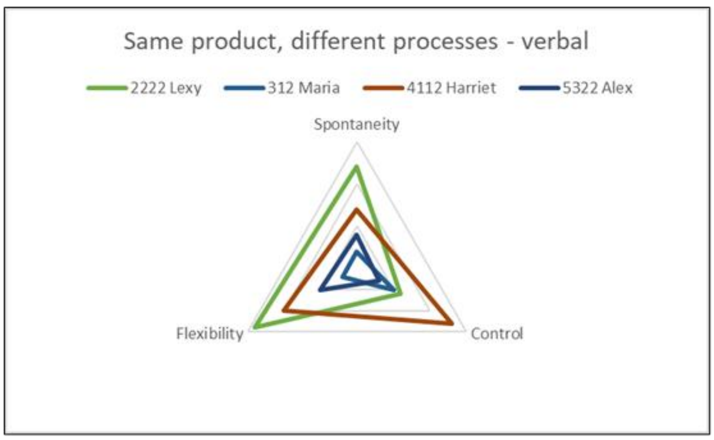


Fig. 8. 6 Illustration of difference between creative process and creative product. All four children had the same score for AUT originality

When we put people in the MRI scanner and ask them to produce creative work, what in their brains might we actually be looking at? Are we looking at an individual who is doing creativity with a high level of EC (e.g., Panda, "My concentration was pretty full on because it was quite hard and I found it a bit difficult so my concentration was 100%")? Or one with low EC deployment (e.g., Parrot, "Relaxed and calm and my mind would be so relaxed… Like it didn't have to work very hard")? Or are we looking at an individual who is using EC differently at different times within the task, or when completing trial 2 vs. trial 1, or with changing stimuli (e.g., Medea, "I just probably I stop for a sec for a few seconds and then I just go back and then it's just different concentration yeah… it's a bit weird cos my brain just changes it all by itself")? If we then consider findings based on compressing all those measures into means, how realistic is it to think that they are telling us anything very meaningful, never mind specific or well-defined, about the brain processes of creativity? Dietrich is not one to moderate his critique (Dietrich, 2007a, 2015, 2019; Dietrich & Heider, 2017), "All current psychometric tests used to look for creativity in the brain are based on divisions – divergent thinking, defocused attention… that 1) are false category formations given their exact opposites – convergent thinking, focused attention – also precipitate creative ideas and 2) result in constructs that still consist of many separate mental processes that are distributed in the brain. For neuroimaging studies, the combination of both theoretical problems…makes defeat certain" (Dietrich & Haider, 2017, p.1).

Yet there remains much to be discovered. "It seems that the time has now come to start from scratch in thinking about how to study creativity if the goal is to relate it to brain function" (Abraham & Windmann, 2007, p. 46). Perhaps a rigorous and bounded interdisciplinary approach could provide a good starting point.

Putting findings in context: Improving creativity as a key 21st century skill

"Creativity is now considered good for economies, good for society, good for communities and good for education" (Burnard & White, 2008, p. 669). In the UK, there have been several attempts to give more attention to creativity in the educational curriculum (Wyse & Ferrari, 2015) and fathoming and promoting creativity has also become an international project (Patston et al., 2021; Sun et al., 2021). In this section, we will look at the bigger picture of creativity – in schools and in society. We will first address the purported ‘creativity crisis’ (Barbot & Said-Metwaly, 2020; Kim, 2010, 2021; Runco, 2015), before considering issues faced by teachers and schools seeking to promote creativity, including possible conflicts with performativity and, by association, EC.

Is there a creativity crisis?

In 2011, Kim published a paper entitled ‘The Creativity Crisis: The Decrease in Creative Thinking Scores on the Torrance Tests of Creative Thinking’. The paper involved an analysis of Torrance tests completed by 272,599 Americans from 1966 to 2008 to calculate norm scores. It looked at changes in creativity over time and changes with age, from kindergarten to adulthood. Among its many downbeat findings was that since 1990, while IQ scores had steadily increased (as described by the Flynn effect; Flynn, 1984), creativity scores had significantly decreased, with the greatest declines in youngest children (kindergarten to third grade). The pre-print research made the front cover of Newsweek ‘The creativity crisis’ (2010) with the by-line “For the first time, research shows that American creativity is declining - What went wrong—and how we can fix it” (Bronson & Merryman, 2010); and the related article suggested that “it's left to the luck of the draw who becomes creative: there's no concerted effort to nurture the creativity of all children.”

The idea that creativity is in crisis, at least in the West, has since become widely accepted in the creativity and education literature (Barbot et al., 2020), with many researchers weighing in with their particular take – e.g., Runco (2015) has suggested that a creativity crisis is being caused by mal effects of technology, particularly social media, in stifling creative potential. According to Barbot and colleagues, all this angst is unjustified, since the basis of it - Kim’s research - is "grounded on problematic empirical decisions, statistical approaches, data representation, and interpretation of findings". Their own analysis of the Torrance norm sets, adopting more robust statistical approaches and adding another slew of data from the latest 2017 norming battery, leads them to conclude there is "no evidence for the notion of a generational decline of creativity, and even less so, for a 'creativity crisis' and that the very suggestion of it "represents a counter-productive societal and scientific myth" (Barbot et al., 2020, p.1).

The most interesting aspect of this ongoing debate is the apparently ready appetite for the idea of a crisis in creativity. Similar concerns (that younger generations are somehow poor imitations of older ones) are also sometimes expressed with regard to literacy, numeracy, and intelligence, in defiance of the actual facts (OECD, 2016). According to some researchers, the tendency to denigrate younger generations is caused by two things: the first, a memory bias which projects one's current self on to one's past, and the second, a tendency to notice limitations in others in areas in which oneself excels - intelligent people are more likely to perceive a decline in intelligence (Protzko & Schooler, 2019). But perhaps there is also something creativity specific here. Many creativity myths persist (Cropley, 2016) and underlying many of them is the persistent idea that creativity is somehow magical, indefinable, mysterious, fragile, and remote. If something is fragile, it is logical to believe it might get easily broken – to be in crisis. In the following sections, as we consider factors which might improve or impede creativity in classrooms, it will be important to shed some of these myths. To understand and improve creativity, a necessary first step is to take it off its pedestal.

21st century education

The OECD has identified creativity, alongside critical thinking, communication, and collaboration, as one of the core competencies of the 21st century (Schleicher, 2011, 2012, 2018). Advocates of the 21st century skills agenda believe that creativity is an essential component of what will help students thrive in today's world (Rich, 2010). The set of skills and abilities comprising EC are increasingly also seen as critical for successful life outcomes (Diamond, 2012, 2013). A large and growing body of evidence supports their positive effect on everything from school achievement (Gathercole, 2004b) to physical and mental health (Crescioni et al., 2011; Diamond, 2013), job success (Bailey, 2007) and quality of life (Brown & Landgraf, 2010). Given these dual targets of creativity and EC, we need to consider whether we can have the best of both. The findings from the training intervention in Chapter 5 show that both EC and creativity are changeable over time, though not for the better in terms of creative originality. The mixed results raise questions about how to boost both EC and creativity if they do not necessarily flourish in parallel.

Cognitive regulation, essentially synonymous with EC (Munakata et al., 2011) has been shown to play a critical role in learning and educational attainment (Modrek & Kuhn, 2017). Both cognitive and behavioural regulation have been proposed as fundamental to learning as, in the context of school and to put it simply, in order to learn one must first sit, listen and pay attention (Corno & Mandinach, 1983; Duckworth & Seligman, 2005; Modrek & Kuhn, 2017; Zimmerman, 2000). The idea of a tension between the skills of learning to pass prescribed tests and creativity is not new. Half a century ago, Torrance drew attention to the fact that "Children are so accustomed to the one correct or best answer that they may be reluctant to think of other possibilities or to build up a pool of ideas to be evaluated later" (Torrance, 1970, quoted in Lambert, 2017, p. 1). Other researchers have described the tensions that exist "between evidencing subject knowledge and promoting flexible and creative learning" (Kyritsi & Davis, 2020, p.11). And others suggest that "as schools place greater emphasis on learning material and taking tests… opportunities for thoughts to flow freely are fewer now than in the past" (Tan, 2015, p.162). Some go so far as to make a causal link between the advent of universal standardised tests in education and declines in creative thinking, advising that, if we wish to sustain creativity, "Standardization should be resisted" (Kim, 2011, p. 294).

Others take a more circumspect view. The recent Durham commission (2019) on creativity and education stressed an urgent need for more creativity and cited the strong evidence that it can be improved, while also saying "There need be no conflict between knowledge and creativity in our education system. Indeed, the opposite is the case – creativity is founded on deep understanding" (James et al., 2019). From a constructivist point of view, one shared by creativity and educational psychology, the idea that knowledge is created rather than transmitted, also suggests potential synergy (Plucker et al., 2004). But it is nonetheless a persistent finding that even teachers enthusiastic about the project to improve creativity struggle to promote it in classrooms, and a widely held explanation is that doing so conflicts with predictable, test-based performance measures. A recent international study looked at implementation of creativity in curricula in 12 countries (Patston et al., 2021) and concluded that "the journey from openly acknowledging the importance of creativity to systematically and purposefully supporting its promotion in the classroom is a long one… despite widespread interest and a productive field of research in creativity, our examination reveals little support for teachers to turn policy into practice."

How to improve creativity

There are essentially three approaches to improving creativity: promoting and supporting factors that help creativity thrive; reducing the influence of factors which impede it; and training it directly. We will deal briefly with each.

Supporting areas where creativity thrives

It is important to recognise that creative thinking applies to all curriculum areas and not just to the arts (James et al., 2019). One need only look to recent Covid-19 vaccine development programmes for examples of extraordinary scientific creativity (e.g., applying computational language models based on natural language processing to the syntax of protein formation in mutated viruses; Creative Biolabs, 2021). Nonetheless, it is also true that some subjects are more enabling of creativity (Boden, 2010). Elton Van Gogh, aged 10, was one of the most highly controlled children in the Chapter 6 qualitative study, critically self-editing more potential responses than any other child. But there was one context in which he permitted himself greater rule flexibility: in artistic ideas. He said “I think art's a less strict kind of… like area. It's like… with art you can really do what you want, you can do loads of different things so that's why I think that's why I was less strict.” In other words, art was the one place where he allowed himself more freedom to explore and experiment. For him, as for others, art provided what might be described as a creativity ‘enabling environment’ (Kyritsi & Davis, 2020).

Creative professionals echo this view. Tristram Hunt, Director of the V&A Gallery in London, describes the fall in the number of schoolchildren with access to art subjects as leading to “a perfect storm of a collapse in creativity… In the face of the fourth industrial revolution, in the face of the digital revolution, when we need more creativity and innovation within our education system, we are systematically stripping it out” (Brown, 2018). Charles Limb, neuroscientist, jazz musician and surgeon agrees: “The most important thing we could do is to get the arts in schools and not view it as optional … because it takes away one of the best options for people to learn how to develop their creative minds” (Warr et al., 2018). Creativity is not all to do with the arts, but their encouragement for exploration, experiment and releasing strictures gives them many key ingredients to help students practice creative thinking.

Not promoting things which impede it. Creativity vs performativity

Picasso claimed that “The chief enemy of creativity is good sense”. No wonder there are “psychological hurdles that must be overcome when encouraging creativity in the classroom” (Plucker & Makel, 2010, p.48), since teachers, students and schools are daily judged on ‘good sense’ measures of performance. Many argue that there is inherent tension between creativity policies and policies that produce performance targets and league tables, and that this conflict “finds some practitioners frozen, as if blinded by headlights, unsure whether the changed values of empowerment, agency, engagement and generativity are real or imagined.” (Craft & Jeffrey, 2008, p. 579).

Teachers and students alike need to be supported to promote creativity, since creativity involves, by definition, stepping into new, unknown, original territory and deviating from the norm (Beghetto, 2005; Kim, 2021). Teachers need encouragement and help to work outside predictable safe spheres and to take risks (Burnard & White, 2008; Kim, 2021) – and they need to reward students for doing the same. This might mean altering some well-established practices. For example, currently when teachers give praise for perfect test scores, they “may inadvertently advocate that children 'play it safe' when they give assignments without choices and allow only particular answers to questions” (Sternberg, 2003, p. 115). To redress the balance, teachers need to not just encourage risk-taking, but to reward it (Craft, 2005, 2006). In an environment in which performance measures are heavily emphasised, parents might also need encouragement and convincing of the importance of creativity (Troman et al., 2007). Regarding EC, perhaps the minds of our students need a similar extra push away from school habits of predictability, goal-orientation, obedience, stability, and focus.

Baer and Garrett (2010) argue that while teaching for creativity in an era of performance accountability can be challenging, these dual goals need not be conflicting, since creative thinking "*requires* significant content knowledge, and thinking creatively about a topic helps deepen one's knowledge of that topic" (p. 6). Moreover, there are many skills relevant to creativity – divergent thinking for example, which can be used both to bolster creativity and to improve subject knowledge. But it needs highly skilled, confident, trained teachers to navigate these paths (Kyritsi, 2018; Kyritsi & Davis, 2020; Troman et al., 2007). In a qualitative study involving in-depth interviews with teachers about negotiating the twin peaks of performance and creativity in a Scottish primary school, one said, "I think there's lots of strengths in the national curriculum. I'm not totally against it, but I think the rigidity that came in was detrimental to creative teaching" (Troman et al., 2007, p.559). Creativity, as we have seen in numerous ways throughout this thesis, requires flexibility.

Training creativity means first taking it off its pedestal

Harriet, one of the children interviewed in Chapter 3, described the technique she used to ensure her picture was interesting and original, "I wanted it to be strange colours so I made sure I didn't do the leaves green and things like that, so sometimes I was just like taking the nearest pen to me or a random pen to make it look like an unusual colour, or I was taking them in an order and just colouring them in different places so that it didn't so that, if both trunks were brown and both leaves were green then I think it would probably quite boring." She had essentially created a colour-randomising algorithm to make the familiar elements in her picture less familiar, because she knew that unusual, even weird things, were creatively prized. Was that ‘cheating’? Would a naïve viewer, seeing the blue trunk of her tree, feel somehow duped to discover that it wasn’t coloured blue to reflect melancholy or to blend with the sky in a statement about eternity – but just because she had picked a ‘random’, ‘unusual’ colour, which might equally have been yellow or red? Similar questions regarding meaning or intent arise with actual algorithms, and the debate about creativity by artificial intelligence (AI) – or Boden’s (2004) ‘unromantic artists.’ Many are doubtful as to whether, even if an AI were to create work which would be judged a masterpiece if made by a human, it could ever be taken seriously (Boden, 1996; Colton, 2012).

At the heart of creativity is the notion of value. And value is unavoidably subjective - debates about the meaning of a creative product to its judge are baked in (Abraham & Windmann, 2007; Hills & Bird, 2018). Perhaps we, as judges, serve to impede progress in training and developing creativity because we do not want to see behind the screen and witness the trick revealed. We want, as judges of creative products, to impute magical meaning, to be entranced. But if we are serious about improving creativity, we need to let go this sentiment. Simon Colton, a computational creativity researcher and creator of AI creative *The painting fool*, says, “Creativity is not some mystical gift that is beyond scientific study but rather something that can be investigated, simulated, and harnessed for the good of society” (Colton et al., 2009, p. 12). If we view the instinctive, mystical components of creativity, as arising not by ‘magic’ but from non-cortical brain structures, it is quite possible to demystify creativity without comprising its sometimes-instinctive origins.

There is a considerable body of evidence which supports the idea that creativity can be trained (Gregory et al., 2013; Runco, 2014; Scott et al., 2004; Zabelina & Robinson, 2010b). It is beyond our scope to fully expand on it, but the range of evidenced approaches includes tactical training (e.g., using tools such as SCAMPER (Michalko, 1991): Substitute. Combine. Adapt. Magnify. (re)Purpose. Eliminate. Reverse), the use of analogies (Root-Bernstein & Root-Bernstein, 1999), focusing on problem finding (Runco, 2014), training in divergent thinking (Fasko, 2001) and a range of artistic, kinaesthetic, dramatic, and multiple-component programmes (Rose & Lin, 1984; Scott et al., 2004), some of which emphasise the spontaneous nature of creativity by creating environments which ‘let it happen’ (Runco, 2014). A thorough quantitative review of creativity training interventions decisively concluded that training is effective, with large overall effect sizes as well as sizable effects in components including divergent thinking and problem solving (Scott et al., 2004). So, what is standing in the way of doing it? As well as the barriers discussed (such as the conflict with performativity and perhaps a wish to preserve the magic), perhaps the biggest obstacle is the persistent scepticism about whether improving creativity is possible (Bereczki & Kárpáti, 2017). Training it means tackling myths, such as creativity being the preserve of the few, that it is born not made, and that it is unyieldingly chaotic and disorderly (Boden, 2004; Cropley, 2016). It is none of these. Using well-established techniques to improve it is as likely to reap rewards as going to the gym is to plump your six-pack. True, “not everyone will be an outstanding weight-lifter, but everyone can build muscle” (Runco, 2014, p.386). Or, as the renowned author, John Steinbeck, put it, “Ideas are like rabbits. You get a couple and learn how to handle them, and pretty soon you have a dozen.”

We know from years of educational, psychological, and neuroscientific research that children get better at what they practice. And the child “does not passively absorb information, but through manipulating the environment, selects the experiences from which to learn” (Dumontheil & Mareschal, 2020, p.44). At the most basic level, are the simplest tools and experiences which could improve creativity being used in schools? Children in regular classrooms should be asked open-ended questions as opposed to those with a single right answer and encouraged to produce as many answers as possible. They should be prompted to develop early ideas, considering implications and implementation. They could be encouraged to experiment with what happens when they let their mind wander, prompted sometimes to say the first thing in their head, without editing. They should be urged to listen to novel sounds, try new smells, look to surprising places as sources for new ideas, given unrelated ideas and tasked with finding a connection. They should be allowed, in a psychologically safe environment, to fail. Moreover, they should be explicitly taught that creativity can be improved, that they can learn how to get better, just as they can with sums or spelling (Gregory et al., 2013; Scott et al., 2004). Our educational strategies, in actively and consistently encouraging order, stability and conventionality are almost entirely focused on the control side of the balance. We need to make efforts to redress the imbalance.

Limitations and future directions

How can science possibly hope to explain the ‘fundamental novelties’ of creativity? (Boden, 2004)? The challenge is enormous, and it is reasonable to question whether our current tools are up to the task. We have already said a good deal in this thesis about the limitations of many of the most popular tests for ‘creativity’ (in particular, the DT tests so often used as a stand in for creativity) and the many efforts to refine and improve them (see Chapters 1, 2 and 5; Baer, 2011; Dietrich, 2015; Forthmann et al., 2018b, 2020; Lubart & Besancon, 2017; Plucker et al., 2004, 2011, 2014; Puryear & Lamb, 2020; Runco, 2008; Silvia et al., 2008). Unfortunately, the gravitational pull of these tests makes them hard to resist, particularly for neophyte researchers. DT tests seem to have got stuck in a logical black hole in which researchers continue to use them, despite multiple problems, chiefly because everyone else does. Ideally, the long term will see the development and uptake of new, better, more reliable tests whose cognitive targets are more precisely defined (Dietrich & Haider, 2017). In the interim, one path to progress might involve using DT tests in more targeted ways, e.g., task instruction could be productively manipulated (Acar et al., 2020; Forthmann et al., 2016) to differentiate fluency from originality (and, indirectly, different cognitive approaches) and they could be used as the basis for verbal protocols (possibly in conjunction with manipulated task instructions) to understand process (Gilhooly et al., 2007). In the empirical work here, we have witnessed a fair degree of change in creativity, through a range of approaches including the use of DT tests but many limitations of these tests remain. In this thesis, the issues concerning originality scoring have been particularly problematic, something others have pointed out, in referring to an inappropriate quantity of ‘researcher degrees of freedom’ on scoring methods (Barbot et al., 2019a), particularly with regard to originality (Reiter-Palmon et al., 2019). These issues inevitably limit the confidence and generalisability of findings.

Much has also been said about the use of verbal protocols as a tool to probe cognitive mechanisms (see Chapter 3; Fazelpour & Thompson, 2015; Johansson et al., 2005; Nisbett & Wilson, 1977; Petitmengin, 2011; Petitmengin et al., 2013; Shear & Varela, 1999). I have attempted to justify their use and to maximise the validity of data obtained from them. Nonetheless, it is important to acknowledge some important conceptual and practical limitations of these methods. For example, how to answer a charge that children might be confabulating? Although some aspects of their account can be checked against external and other internal clues (for example, video evidence supporting statements about the order in which events occurred), when it comes down to the fine detail, it is almost impossible. It is particularly so for aspects which, even with a truth serum, would be very difficult to decipher. Take Medea's account of the origin of her idea to use a massive paperclip as a surfboard: at first she said, "I have no idea where that came from," then, on further reflection, added, "Cos I think I looked at this [the curved end] and cos it's quite similar to a surfboard and you could stand on that and just go weeee," and then, after still more reflection, said, "I think I just know now cos a chain [her previous response] cos I was thinking of a chain ferry in the water…yes I was thinking to do stuff with water like chains and anchors that's probably where that came from." The problem here is that her responses could be at once veridical and confabulated – and it is not possible for the researcher to distinguish imagined from real memories. While best efforts were made, first to improve validity, and second, not to focus unduly on single responses but rather overall patterns, these profound questions remain.

Looking to the future, new methodologies which put the 'self, back into self-report' are beginning to gain traction. For example, Cotter and Silvia report, in a recent special issue on creativity methodology (Psychology of Aesthetics, Creativity, and the Arts, 2019) on their use of 'experience sampling' to gain insight into real-world creativity. The idea is to assess people's creativity in their natural environment, through prompting them at random intervals, typically over long periods, to record responses to particular thought probes. They suggest that these sort of techniques, as useful accompaniments to lab-based approaches, particularly allow fleeting and spontaneous aspects of creativity to be captured. The issue's editors also note that "Self-report methodology has received surprisingly positive praise in this special issue," perhaps a sign that creativity research methods are getting more diverse – and more creative (Barbot et al., 2019a).

As the use of real-world and qualitative tools becomes more established, the field of creativity researchers will face the challenge of how to unite findings from these approaches with more traditional quantitative, lab-based results. Again, the challenge of bringing mixed methods together has been (intensely!) experienced in this thesis (see Chapters 4 and 7), with sincere efforts to candidly explain the choices made. It nonetheless needs to be acknowledged that other choices were possible, a statement which raises questions about the nature of the knowledge itself. "Scientific knowledge is a social, creative, tentative human product that involves many different methodologies none of which relies on an automatic processing of data" (Gasparatou, 2017, p.6). Advancing the sort of interdisciplinary approaches advocated here will require the sort of epistemological flexibility which will not be to everyone's taste.

A final set of limitations relates to development. I find myself still haunted by a picture created in the first study by a child of 4, the youngest in the sample. Presented with Torrance's egg-shaped stimulus shape (Fig. 8.6, left), most children draw some sort of figure - a person, an animal, an alien, a chicken, with more unusual responses being a flower or perhaps a celestial body. What happens in the brain of a child who produces the drawing in Fig. 8.7 (right), entitled, '*Somebody put a rock in the bathroom and now we can't get to the toilet'*?

Fig. 8. 7 Torrance stimulus shape (left) and (right) the drawn response of a 4-year-old child (annotations dictated by child, written by researcher)

Is this just a hole in one, the apparently magical moment when, pushed by the desire of the imagination to be embodied (Vygotsky, 1930), originality strikes gold? Or are there particular clues in the fact that this child was so young? Is creativity somehow easier for the young, with partially formed concepts? Is there something serious to consider in the idea, attributed to Picasso, that “Every child is an artist. The problem is how to remain an artist once he grows up” i.e., the view that imagination gradually surrenders to reason and intellect, and that emotion gives way to knowledge? If so, is this linked to the development of EC, the scaffold on which reason is built? In this thesis, which has only studied children, a limitation has been that we have related findings primarily to adult models, with the assumption that the same processes are at play. In doing so, perhaps there has been insufficient consideration of the possibility that there is something distinct, over and above differences in EC development, about the creativity of children.

Conclusion

Anna Burns, winner of the Man Booker Prize for her novel *Milkman*, said of it, “The point is, I can’t intend anything in my writing, or demand anything of my writing. I have no idea what is going to come” (quoted in the Guardian, 2018). Joan Miró, renowned Spanish painter similarly claimed, “When I stand in front of a canvas, I never know what I’m going to do – and nobody is more surprised than I at what comes out” (Fundació Joan Miró website). Alexander Fleming, physician, microbiologist and inventor of penicillin, described how “One sometimes finds what one is not looking for. When I woke up just after dawn on Sept. 28, 1928, I certainly didn’t plan to revolutionise all medicine by discovering the world’s first antibiotic.”

These stories of creativity attest to its most surprising and spontaneous aspects – those that enable the magic, the thrill of the hole in one. They are an important and exciting part of the story. Yet any of those creators might also have spoken of the graft, the never-ending experimentation and failure cycle, the tenacity, the discipline, the focus needed to turn their magical sparks into magnificent blazes. Ferran Adrià, creator of Spain's elBulli restaurant and often described as the world's greatest chef, conjures these other aspects when he says, "Our work is systematic: you have to be very organised to achieve a sense of anarchism… Last year we ran 4,000 tests and only about 300 of them panned out…The important thing is to have lots of ideas simmering" (Hoffman, 2009). And the artist Louise Bourgeois (quoted in *Intimate Geometries, Storr, 2016*) captures both aspects when she says, "The realistic drawings are a way of pinning down an idea. I don't want to loose it. With the abstract drawings, when I'm feeling loose, I can slip into the unconscious."

Through this thesis, we have seen this duality play out in the contribution that EC makes to creativity. Its effects can be positive - both broadly, in keeping children on track and on task, and narrowly, through juggling multiple ideas and ruling out those which don't make the grade. They can also be negative, denying the 'letting go' sometimes needed to find remote and unusual ideas and add surprise. In the context of schooling, and education systems which focus on performance, good behaviour and standardisation, this sort of 'letting go' might not only be hard to achieve, but even counterproductive, in view of the designated goals. While there is considerable emphasis on training EC-relevant skills in schools, there is no equivalent prominence given to training spontaneous thought processes. Some might even deem the notion of 'training spontaneity' oxymoronic. But it is not. And not only is it possible, it is vital, if we are to nurture and develop the full range of skills children need to be able to truly create.

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Appendix

Appendix materials

Chapter 2

Promotional materials for ‘Bright sparks’ event
Torrance tests of creative thinking – figural tests 1, 2 and 3

Chapter 3

Picture and object stimuli for creative product (story or picture)
Example creative works - a sample of stories and pictures produced
List of interview questions
A priori coding scheme
Idiographic thematic narratives not included in main text

Chapter 5

Letters to head teachers
Letter to parents/carers
Information sheet for children
Instruction manual for teachers for EC intervention (Nelly and Noah)
Instruction manual for teachers for control group (Traditional games)

Chapter 2 appendices

Flyers / trifolds for Bright Sparks event:

BRIGHT SPARKS

Come and learn all about how your brain works!

FOR FREE!

FREE HALF TERM CHILDREN'S ACTIVITIES

Weds 31st May –
Fri 2nd June 2017
Birkbeck,
University of London

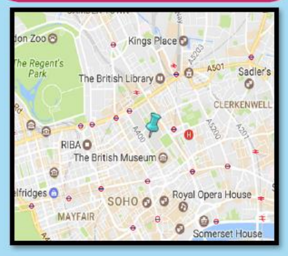
I've got something on my mind!

How do I sign up?

Signing up couldn't be easier – just fill in our online form and choose the session you want. Bright Sparks is very popular so do sign up early.

Where we are

Euston, Goodge Street, and Russell Square stations are all within 10mins walk.



Who we are

About us

Bright Sparks is an initiative run by PhD students from the **Centre for Educational Neuroscience**.

All scientists and helpers are fully DBS-checked and have experience working with children.

To find out more and sign up:
www.educationalneuroscience.org.uk/bright-sparks

Birkbeck, University of London,
Malet Street, Bloomsbury, LONDON.
WC1E 7HX

Centre for Educational Neuroscience

Birkbeck UNIVERSITY OF LONDON

UCL Institute of Education

Are you looking at my brain?

What is Bright Sparks?

Bright Sparks is a fun-packed half term event for primary school children. It's run by real scientists – very friendly ones, who don't wear white labcoats! – from the psychology department of Birkbeck, University of London.

Not only will you get to roll your sleeves up with heaps of fun activities all about the brain, you will also take part in real scientific research and help scientists understand more about how children's brains work.

What sort of activities will I get to do?

We have quizzes, computer games, brain jigsaw puzzles, modelling with neurons, machines you control with your eyes, and a project to make enormous 3D brains.

"Bright Sparks was brilliant! I had the best time. It was so cool to know that real scientists were studying me and my brain."
Nathan, aged 9

What actual scientists look like!

And what about the science experiments?

The scientists working at Bright Sparks are interested in all sorts of things about how the brain works – from how the brain recognises faces to where new ideas come from, from how we learn language to how we balance.
In the experiments, you will do simple tests on computers or in the real world; they're super fun to do and also give the scientists lots of information about your brain.

A brain teaser in need of a brain-wave

How long will I stay?

We have six sessions available:

Morning or afternoon on:
Wednesday 31st May
Thursday 1st June
Friday 2nd June.

Morning sessions run 9.30am to 12.30pm.
Afternoon sessions run from 2pm to 5pm.

Drinks and snacks are provided free of charge.

Parents have a chance to ask any questions when they drop children off.

Torrance Tests of Creative Thinking: Figural tests

FIGURAL ACTIVITY 1

On the page I'm going to give you is a shape. Think of a picture or an object which you can draw with this shape as a part of it.

Try to think of a picture that no one else will think of. Keep adding new ideas to your first idea to make it tell as interesting and exciting a story as you can.

When you have finished your picture, think up a name or title for it and write it at the bottom of the page – or I can write it for you. Make your title as clever and unusual as you can and use the title to help your picture tell a story.

You will have 5 minutes to do your picture.

OK? Let's go!

YOUR TITLE: ______________________________

FIGURAL ACTIVITY 2

I'm going to give you a piece of paper with lots of unfinished shapes on it. By adding lines to these shapes, you can draw some interesting objects or pictures. Try to think of pictures that no one else will think of. Also try to make your picture tell as complete and interesting a story as you can, by adding to and building on your first idea. Make up an interesting title for each picture and write it at the bottom of each one – or I can write it for you.

OK? Let's go!

1. ______________________

2. ______________________

3. ______________________

4. ______________________

5. ______________________

6. ______________________

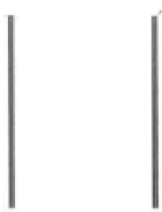
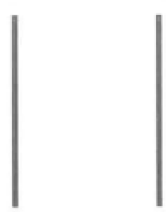
FIGURAL ACTIVITY 3

I'm going to give you a piece of paper with lots of pairs of straight lines on it. By adding to these lines, you can draw some interesting objects or pictures. The pair of lines should be the main part of whatever picture you make but you can draw between the lines, on the lines and outside the lines – whatever you want to do your picture. Try to think of pictures that no one else will think of. Make as many different pictures as you can and put as many ideas as you can into each one. Make up an interesting title for each picture and write it at the bottom of each one – or I can write it for you.

OK? Let's go!


1. ________________ 2. ________________ 3. ________________


4. ________________ 5. ________________ 6. ________________

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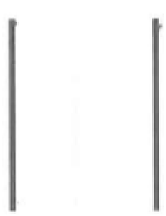
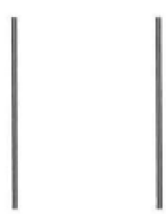
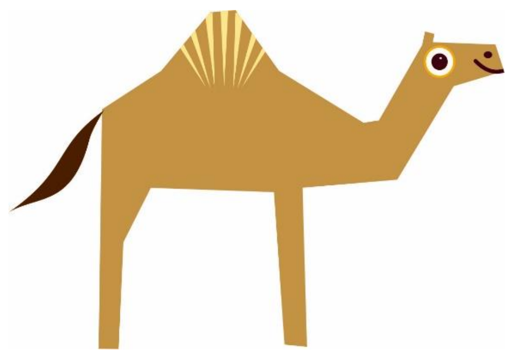



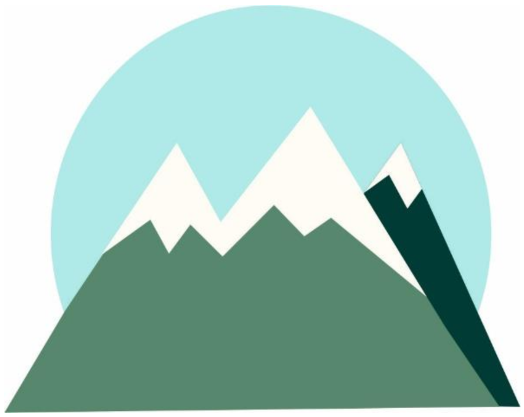
10. ________________ 11. ________________ 12. ________________

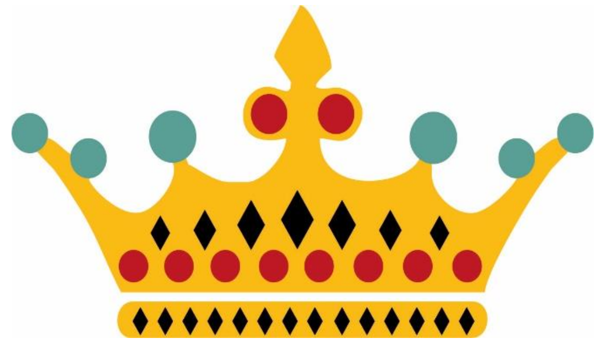
Chapter 3 appendices

Object stimuli for storytelling (animals, imaginary being, place, object)

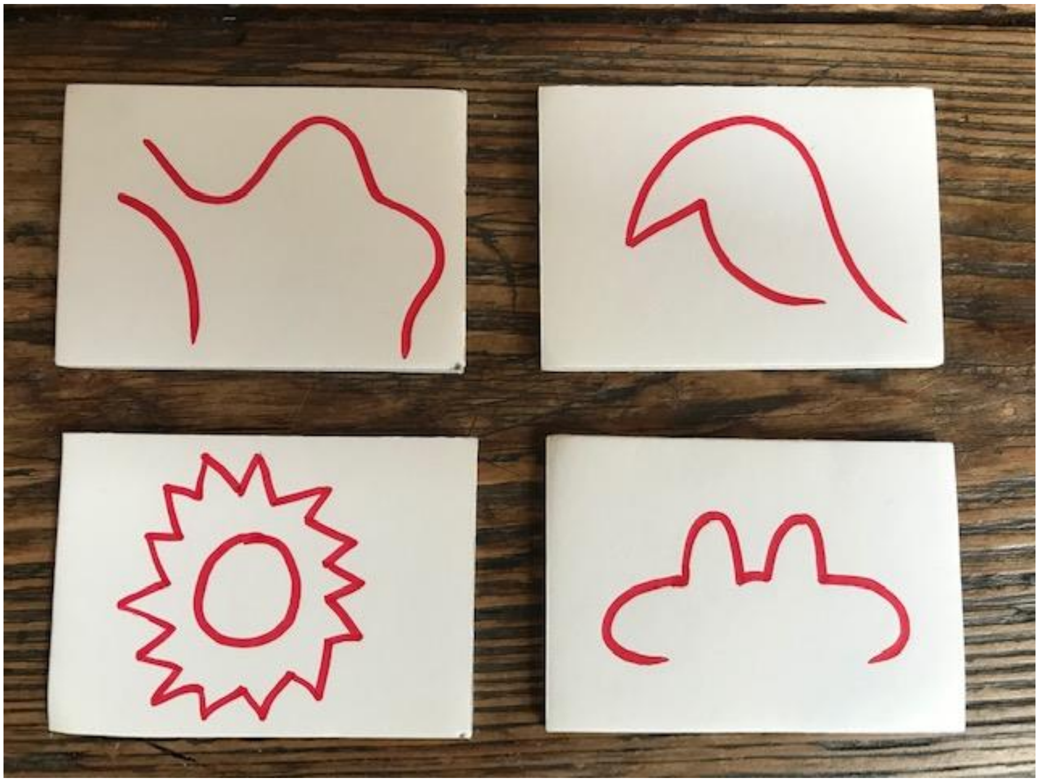


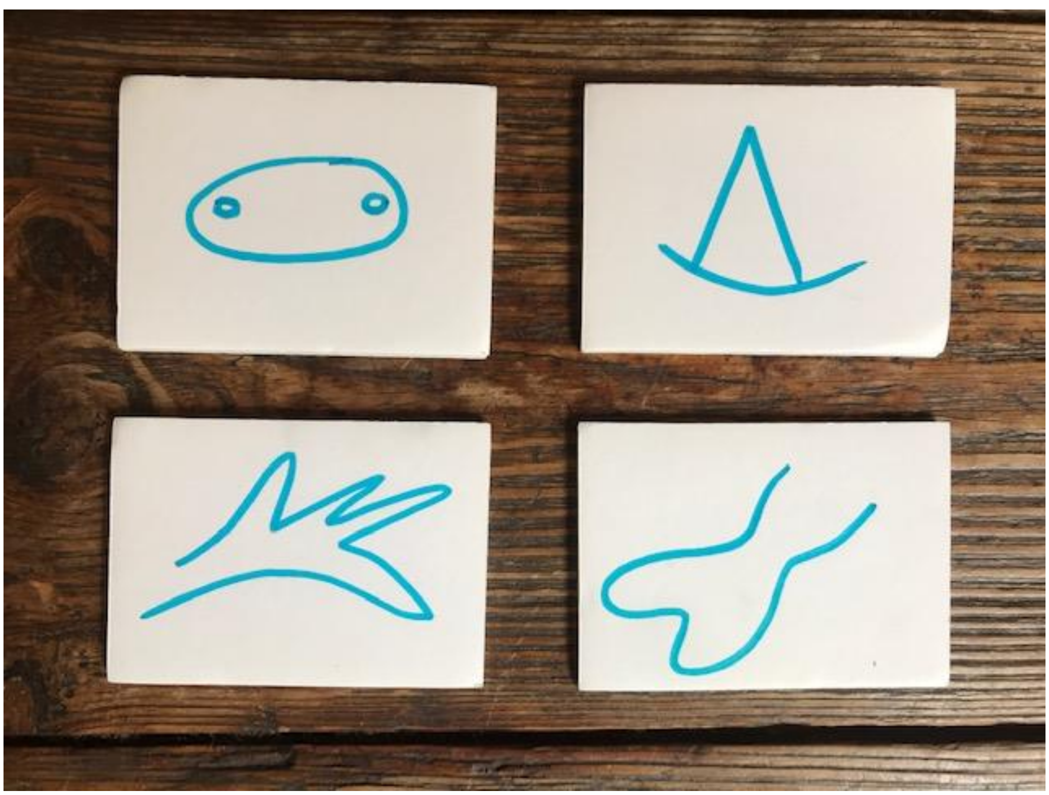



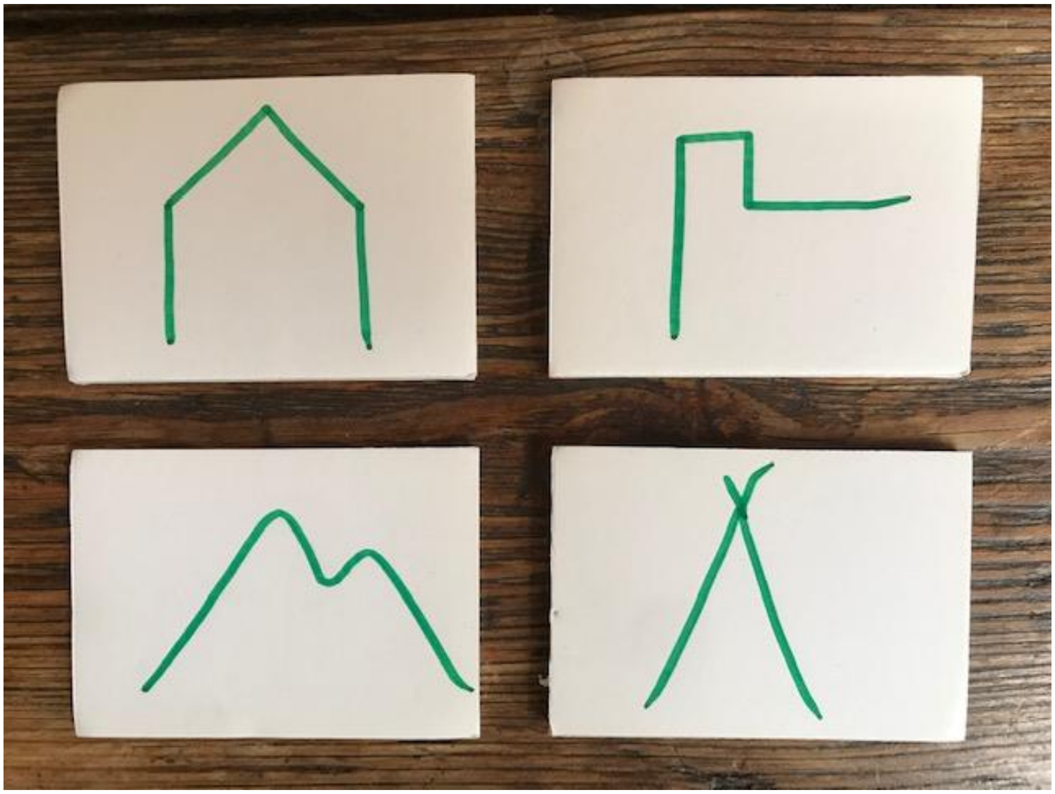


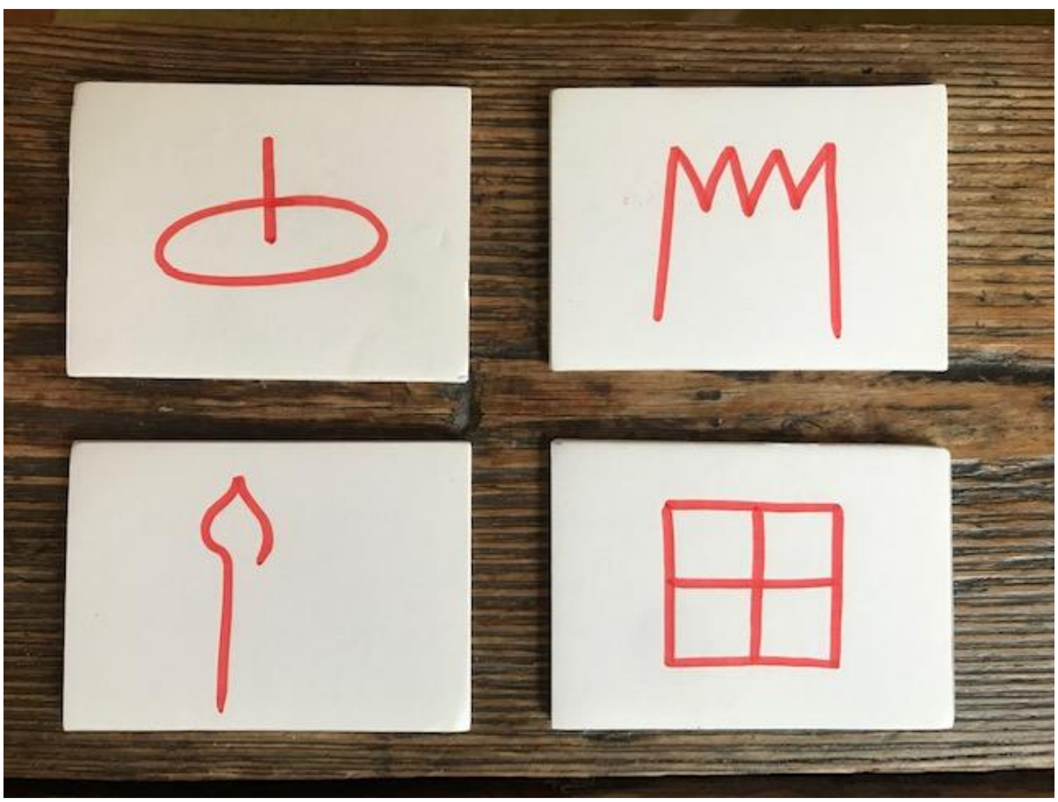


Object stimuli for drawing









Example creative works.

Imagination Creation story transcript. ‘A new species’

[pictures chosen: teepee, (monkey), dragon, candle]

One day there was a mad scientist and he was he was trying to do experiment to duplicate, duplicate objects and things like that and so he had need a lot of emotions and he also needed heat. And then he was in his um one day he was in his um peetee? teepee working out what, how it might work and then he but he I think he put something or he he pressed the wrong button and then a teleporting wall appeared and then a dragon flew out with a speed and it knocked him out. And then and then he the dragon wandered around in the jungle and then monkeys came and pressed the button that duplicated bananas, and then bananas started falling like rain. And then they turned into corn because it was a very hot day and they wanted to watch a movie but there was no popcorn and then their… seeds? – what are they called the popcorn things? Corn? I think it was corn, yeah and it was very very hot so they baked them and the corn into popcorn and there was chaos, everyone was fighting around for popcorn and then it was movie time and then the scientist woke up and he made everything all right. So he put the dragon back into there and then he told the monkeys not to do that again, he also watched the movie though so he was a bit naughty and then he put everything right and then he knew how to duplicate things and everything came out well. But there was still one animal seeking round from the teleporter. It was a… it was a… because when the monkey hit a button it hit it didn’t only hit a button, hit a banana it also hit a snake and a chameleon and a lion and they combined and that was but it was very small and it was sneaking in the jungle.

Finished!

[Int. The end?]

Yeah there was a new species

[Int. Is that really the end. Can’t we hear what happened then?]

Next chapter. Next year erm, next year hmm, there’s now, there was completely a new species, it is – no, what do you say lots and lots of years later?

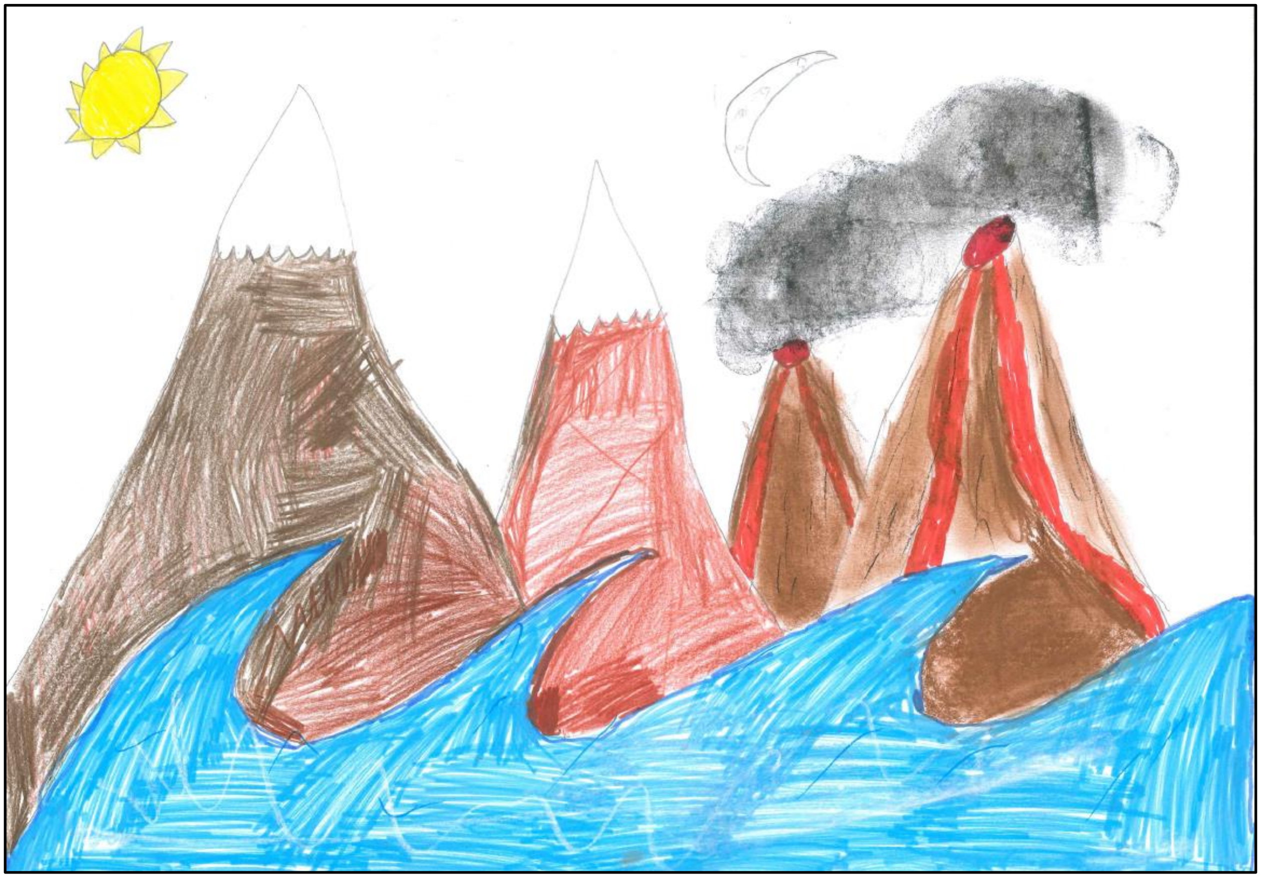
[Int. decades later? Centuries later?... Millennia?]

Millennium later, millenniums it’s like lots of years later and now the species has grown and now there’s not no more animals animals that are now, there are different animals: kangaroo monkeys, hmm let’s see, fish, fish, fish jellyfish, erm, camel sharks and yeah. And then something went wrong in their mind and they started helping mere humans. No no not nothing wrong with their mind but something changed in their minds and they kind of helped humans and so yeah they helped build spaceships things like that and kind of like the animals the nature made friends and no one lived in agony again. Yeah. the end.

Drawing by Lexy

Drawing by Alex

Drawing by Kitty



Drawing by Silky

Core questions for interview

What did you first think when I told you what you were going to do?

Did you understand what you had to do? (follow up)

How did you feel about what you would have to do?

What were your thoughts when you first saw the pictures/words? (encourage to talk precisely through each stimulus in turn, reasons for rejection / selection / modification etc.)

Did you like some pictures/words more than others? What happened in your head?

What was the order of your thoughts? Can you talk me through them?

Did some pictures/words help you think of stories/pictures more easily? What happened in your head? How was it different?

Can you tell me where these thoughts came from? How did these thoughts lead to the next ones?

Did you ever feel stuck? What did that feel like? What did you do then?

Did you ever think of something for the story/picture but then decide not to do it?

What happened in your head then?

Do you like reading stories / doing drawing at home?

Do you ever make up your own stories / pictures?

What sort of stories/pictures do you make up?

Where do the ideas come from?

How did you find it to make up this story / drawing?

How were you concentrating when you were thinking about your story / picture? Can you describe it?

Did you find your mind wandering to other things? What things?

What do you think an idea is?

Do you sometimes think of good ideas and sometimes bad ideas?

Tell me more about that

How can you tell what's a good idea?

Would it have been any different doing this at school instead of at home? How?

Can you tell me anything else about what happened in your head while you were doing this?

A priori coding framework

Aspect of interest	***Subcomponents***	***Illustrative example (what child might say in Alternative Uses Test or TTCT Figural)***	***Name of code***
Creativity components			
Memory	Short term	I just saw the door handle and it looked like the same shape as a pencil	Short term memory
	Long term	I read a story about a boy who made a rocket using an old water bottle	Long term memory
	Direct experience - something the child has done	I used pencil sharpenings to make a collage of a fish in art club	Direct experience
	Indirect experience - via stories, films, hearsay, cartoons	In a movie I saw, a girl sent a message to a pirate and she used an empty bottle	Indirect experience
Association	Combining two or more elements to make a new idea	I thought of a bottle holding things then I thought it could hold air and I suddenly thought of a diver with a tank of air on their back	Association
Extension	Getting to new idea VIA another idea	At first I saw it as a stick but then I thought it could actually be a whole tree	Extension
Insight	Sudden moment of seeing an idea	I just suddenly thought of a tent peg!	Insight
Using analogies or metaphors	Finding parallels which shed light on the topic being considered	I thought of lots of pencils lined up and in my mind I pictured a fence	Analogy metaphor
Redescription / mental	Changing aspects of the stimulus to	I thought what if the pencil was absolutely massive, it could be like a telegraph pole or a	Reconfiguration

manipulation	see it in a different light	traffic light or a flagpole outside Buckingham Palace	
Theory of mind	Putting yourself in someone else's shoes to come up with ideas	I thought about what my friend Charlie might think of because he's really crazy and always comes up with crazy ideas	Theory of mind
Evaluation of ideas	Looking through options	I could think of a lots of different ideas for things you could put in a bottle	Evaluation process
	Testing against demands	I think 'my granny's teeth' is the best idea cos other people won't say that	Evaluation decision
Serendipity	Taking creative advantage of something happening by chance	The pencil fell on the floor with a crash and then I thought I could use it as a drumstick	Serendipity
Experimentation	Trying something out for the first time	I haven't ever drawn a ladder but it's just really easy I discovered	Experimentation
Imitation or simple reproduction	Repeating something done before	I always keep a bit of the eye white so it looks like it is shiny	Repetition
Imagination	Involvement of something that does not exist in real world	I prefer drawing imaginary things because then they can be like whatever you want in your head	Imagination
Don't think…act	Getting out of a rut by just drawing, scribbling, talking, doodling etc	I was stuck and so I just drew some random lines	Don't think…act
Divergent	Having lots of	As soon as I saw it just loads of ideas came into	Divergent

thinking	ideas in very quick succession or simultaneously	my mind	thinking
Convergent thinking	Evaluating the best of candidate ideas	It took me ages to think about all the ideas and work out which one was the best	Convergent thinking
EC components			
Cognitive inhibition	Fixedness. Not being able to see around an idea	Once I'd seen it as a moustache I couldn't think of anything else it could be	Fixedness
	Deliberately ruling out obvious answers	I thought it looked like a tree but then I thought everyone would think that because it was a bit too obvious	Inhibiting obvious
	Failing to rule out obvious answers	I could use it as a container for pebbles, or a container for buttons or a container for stones	Not inhibiting obvious
	Ruling out previously given answers or ideas	I'd already done one which looked like a building so I thought I should try and do something different for this one	Inhibiting previous
	Failing to rule our previously given answers or ideas	It could be a rocket. Did I already say that?	Not inhibiting previous
Behavioural inhibition	Sitting still, being quiet	When I started I was thirsty but I thought I'll do this and then I can get a drink after	Behavioural inhibition
	Not sitting still or being quiet	Sometimes I just need to run around or dance or something	Lack of behavioural inhibition
Social inhibition	Not saying	My mum once made me wee in a bottle but I	Social inhibition

	answers which might sound silly or embarrassing	didn't think that would be very nice to say!	
	Saying answers which might sound silly or embarrassing	It could be for poo and wee in an emergency	Lack of social inhibition
Attention	Selective attention - ignoring distraction	I could hear clattering next door and I wondered what they were doing but my teacher tells us to try and ignore that sort of thing	Acting to stop distraction
	Lack of selective attention	I could hear clattering next door and it made my mind go blank	Being distracted
	Distraction leading to an idea	I heard all that clattering and that made me think I could use it as a percussion instrument	Distraction ideation
	Sustained attention	I was concentrating really hard the whole time and the time just went so fast	Sustained attention
	Lack of sustained attention	At first I was concentrating but then I just found my mind jumping around all over the place and that's why I never finished that picture	Lack of sustained attention
Switching	Deliberately moving on to a different subset when one set exhausted	I couldn't think of anything else to do with making the lines into people so I stopped thinking about people and made myself think about types of transport instead	Task switching
	Switching from deliberate to associative mode of thought or vice versa	I stopped trying to really think hard and just sat back for a minute	Mode switching
Goal planning	Consciously scheduling an	I couldn't think of an idea for this one so I went straight on to the next one and thought I would	Planning

	order of activities	come back to it later	
	Consciously scheduling overall speed	I was drawing so quickly and thinking about the next one even while i was l doing one	Scheduling
Working memory	Using idea still in working memory to combine or adapt to produce a new idea	I thought they could climb up the clouds and then I thought about mountain climbers having a new kind of competition to see who could get up the clouds the quickest	Working memory ideation
	Putting an idea down as word or picture to get it out of WM	I just put a bit of a line there to remind me to do the fishing rod later	Working memory offload
Strategising	Realising a new approach is needed and deliberately deciding on one	I was stuck and I tried different things like thinking what my teacher would say, or screwing up my eyeballs	Strategizing ideation
Taking a step back	Taking a moment to get an overview	I kind of sat back to see what the whole thing looked like	Step back
	Taking a moment to switch off	My brain was just too busy so I decided to just switch off and think about nothing for a minute	Defocus
References to emotional state	Positive affect	Excited, happy, looking forward	Positive affect
	Negative affect	Anxious, nervous, worried	Negative affect
	Neutral affect	Calm, bored, relaxed, fine	Neutral affect

General description of state of mind	Inactive state	My mind was blank, I had no ideas	Blank brain
	In a very active state	My mind was going crazy	Busy brain
Personality aspects	Openness to experience	I always love trying out new things	Open to experience
	Tolerance of ambiguity	I accidentally did that guy's face upside down but then I decided it looked good like that	Tolerant of ambiguity
	Risk taking	I had no idea what I was going to draw so I just jumped in and hoped for the best	Risk taking
	Perseverance	It took ages to get it to look right but I really wanted it like that so I just kept going	Perseverance
Contextual references	Positive reference to school environment	It would be great doing it at school cos we have loads of good materials	Positive school
	Negative reference to school environment	If I was doing it at school I wouldn't have done as much crazy fun stuff	Negative school
Help factor	Reference to factor which helps creativity	I find I have most ideas when it is nice and quiet	Creative help factor
Hindrance factor	Reference to factor which hinders creativity	If I am just sitting in a dark room then I won't really have any ideas in my head	Creative hindrance factor

Constraint	Reference to rules or constraints	There are too many things to try and fit in so I just ended up not having a single idea	Constraint
Value by self	Positive self value	I'm normally happy with it and I like it however it turns out	Positive self value
	Negative self value	I normally hate what I do because I'm not really good at drawing	Negative self value
Value by others	Positive value awarded by others	I sometimes show my pictures to my mum and she usually says I am very creative	Positive external value
	Negative value awarded by others	If I think it is good I might show it to my friends but if they say they don't like it then I don't know if it is really good any more	Negative external value
Embodied cognition			
Physicality	Using physical movement deliberately	I had run out of ideas so I just started doodling to get some more	Doodle
	Body leading the mind	My hand just started drawing it without thinking	Hand first

Idiographic thematic narratives

Ben 10. A free flow of great ideas – but mostly they are not allowed in

Ben was very clear about what he was going to draw before we even began (I know what I'm going to draw) because he is very taken with particular subjects (I felt mmm more into superheroes). To that extent, his interview is less informative than some as to creativity as it more represented reproduction from memory.

The way in which he approached the sparks was more to look for something that would 'go' rather than looking for new ideas (It's because they all don't really look like… like one I really want). He was not keen to incorporate new ideas into this schema (not really much tents in superheroes) and on the occasions when he was tempted by one of the stimuli it was because it gelled with his pre-existing plan (I could have chosen it [alien] because Vilgaxe is an alien). There were one or two occasions on which this approach was successful through a triumph of spontaneous associating (The sun. Cos I could use it for a for a mask on one of them so like draw a sun then draw some eyes in it. But then it made thought me of Heat blast because the sun, the sun's fire and Heat blast's made out of fire). As such his approach represented, in terms of dual process theory, an approach to creativity based on persistence (ploughing the same seam at increasing depth) rather than flexibility, something he found hard (you could do that but I'm more into stick men)

He produced some highly original ideas which emerged apparently spontaneously from seeing the sparks (this one looks like a pond with a raindrop going in; this one looked like a giant foot; (this) made me think of… Rip jaws because he goes under the sea and his claws are really sharp and that looked like a king's crown but it was more sharp). But in evaluation he was very strict. If it didn't go, it wasn't in. So in some ways, he represents an ideal of creativity – very open to original and bold ideas in generation and very exacting in evaluation. But perhaps the bases of his evaluation was too limiting – it essentially had to be in Ben 10. Despite his young age (6) he was aware of the slight paradox he faced in coming up with plenty of ideas but none of them quite gaining traction (It's because nothing really went in my drawing well but it did put ideas).

Dooda. Metacognitive control and creative problem solving

To describe Dooda's creative thinking seems to describe the mental workings of someone much older than 7. Enthusiastic about new things (I just wanted to give it a first shot) she appreciates that only through experimentation and practice will she learn and improve (if try something that's new then I can draw it again in other pictures that I do) but this exploration does not come easily (I was feeling a bit scared). Nonetheless, she strikes a balance, generally favouring experiment (what if something goes wrong and they're not the same size? But then I said ok I'm just going to try).

She seems naturally to produce ideas both spontaneously (a frog!) and with effort (I'm trying to think of a shape that it's in…) and both with success in finding ideas beyond the obvious. She recognizes that ideas feed in from experience (in a museum you've got different types of things like ancient Egypt, dinosaurs…it really gets my brain to think) and also from direct action (when I start drawing it give me ideas and the more further it comes the more ideas it gives me). The only trouble with ideas is when there are too many to decide on (when you think of lots of things well my head just starts hurting and I had a headache) though even here she managed to produce a great metaphor (you know when you keep on saying [ie speaking], your throat hurts…that's how my head hurts).

The ‘beyond-her-years’ part is particularly when she is evaluating ideas. She is unusual in bringing generative creativity to this part of the process, creating new categories which form the basis for judgement (I, first I think of one reason why and then I think which one is the best reason and then I pick that one), often formulating complex algorithms for decision-making. This allows her to scrutinize each idea meticulously (I was going to pick it but I said no to myself). She was highly aware of time and efficiency throughout the process (It’s good to take your time just like an artist would do) and, based on previous bad experience (it just ends up a big mess because I always rush) told herself on several occasions to take her time (I wanted to rush but I said no) and to stay true to her well-conceived plan (if I went like castle, then table, castle table castle table, I might do something wrong, if I forget my plan, but I don’t want to forget my plan, so I do it in order).

She has a poetic turn of phrase, partly a product of her young age (It looks like a bird like when its beak is down and it’s coming into its wings or [of candlesticks] they glow… but at night you have to candle them up) as well as creating the notion of Idealand in her brain as the place where all ideas come from (Idealand… that’s in my brain).

Silky. Walking the tightrope of freedom and control

I feel less confident drawing conclusions about Silky since she was so quiet in the interview. There was not a huge amount of spontaneous talk, it was more coaxed talk (‘not that much’, ‘sometimes’, were very common answers).

With that caveat, some observations can be made. The first was a very high degree of concentration throughout her drawing. She took nearly an hour to complete it, during which time she appeared completely absorbed in her work, despite many distractions going on around her ([did you notice your mum reading your brother a story?] not that much). She was in a state which I think could be fittingly described as flow ([were you having to make an effort to concentrate? I was just concentrating), in the zone, in the moment. She did not look up and worked continuously and conscientiously throughout.

So was this a picture of simple control? Some evidence suggests not. She showed great freedom of expression with her materials, with a range of movements from very precise and gentle to big and vivid. She was the only child who didn't mind in the least the pastel dust all over her fingers and made no attempt to wipe it off – in fact she explicitly liked smudging and blurring (I like doing the smudging). She started with a definite idea that she wanted to do a drawing from an Enid Blyton book but was open to incorporating new stimuli which weren't in the original (I just added it) and was happy to proceed without a plan ([The other ideas came as you were doing the picture? S. Yeah). In short, she seemed content to balance a degree of control with several degrees of freedom and a recognition that things yet unknown might prove worthy of her attention. Similarly, she balanced a propensity for the imaginary (I like using make believe things) with certain self-imposed constraints (I thought of a monkey but I didn't really want to do a jungle so I chose a frog) as if it were impossible to envisage a monkey in a make believe scenario. In other ways, she was happy to adapt (I used them in my different ways by adding a bottom to this one and adding like a playground sort of like at the bottom here). When things went wrong, she calmly problem solved her way out of it, showing both emotional control and mental flexibility (I tried the white one but it didn't work then I tried it on top of another one and it worked).

I would characterize Silky as a quietly confident creative, with a naturally experimental nature coupled with the problem-solving abilities to get herself out of a hole (I smudged it with my arm by accident but I…I put the dark green on my frog so that if I put my arm on it, it wouldn't smudge).

Maria. Balancing control and spontaneity, with control usually winning out

Maria combined high motivation (I was just excited and pleased that I would get to do drawing) with a desire to produce high quality work (you want it to be really good). She went about the task with a very high level of planning (you have to test it out see if you like it first) even investing in a labelled test area separate from her drawing. This control included acting to prevent unforeseen errors ([if] you don't like that colour you can't erase that with those pens). On occasions when small errors did, inevitably, arise, her responses favoured control over flexibility. In one case, she applied experience from memory (sometimes if you do that…if you kind of draw another line then it goes even more wrong) before deciding to accept the error (so I just left it as it was); in another, she resisted an opportunity to go in a new direction, preferring to keep to the original plan (I wanted to stick with blue).

She describes a balance between control and spontaneity (I knew what bits of it might look like but when I got into it I just started doing it as I went along), recognizing the need, at least in execution, to sometimes go with the flow. This perhaps applied particularly to a sense that sometimes the body might know better than the mind (it's easier to do it with your hand instead of squinting and looking at it). In her description of a tightly controlled protocol for drawing a cat (that technique is kind of stuck in my head) she outlined five or six strict rules, before allowing for a small degree of freedom (you can colour it the way you want it). Similarly, in drawing windows on her house (you need a window… because otherwise it would be really dark) and applying logic in what you could see out of them (if you look out of one window upstairs you're more likely to see it downstairs as well) she made the concession of leaving out the traditional cross (cos I want to see straight forward into the mountains). In short, there was little room for spontaneity or the unexpected. On the rare occasions when ideas arose uninvited (oh yeah that popped into my head) she acted quickly to control them (sometimes you forget your ideas so I'm going to jot it down as soon as possible).

She had little time for things which were weird (that would just look kind of weird and not very nice), disorganized (it's all mixed up and higgledy piggledy) or too much trouble to execute (I just wanted it simple and straightforward). Rather, in line with her preference for control, she preferred things to resemble reality (I used the pastels and smudged it to look like it was actually real; it looked much nicer and more real).

Alexandra. Drawing from memory is the safest way to ensure creative success

[NB English was not Alexandra's first language and some issues might have been the result of trouble finding the words]

Alexandra's approach to the task was based on an apparently vivid memory of a particularly scene (in my house in Greece when we go swimming the sea… I watching lot of hills). She wanted to recreate this image - and not for the first time - rather than to attempt something new and experimental (I have already my picture). As such, stimuli were chosen very much to fit in with this chosen course rather than to take things in a new direction (I wanted to have people normal).

There was one example where she did something unusual – which was to turn the paper so that it was portrait rather than landscape orientation. When I asked her about this she said she decided to do that when I inadvertently made it possible (when you said that we don't have rules), suggesting that her idea of rule-breaking is quite modest. Her manner was quiet and contemplative- and the fact that her ideas for the picture came from processed memories rather than spontaneously created novel ideas, suggests that this might be typical for her (When I was stuck, I think a little bit and then I draw). Her descriptions of how she absorbs the world around her also gives a picture of someone who is non-impulsive, who takes time to take things in and digest them (sometimes in London where I am sitting and reading I watching of the window the sun and go down and I thought…if you will get very near the sun it will be big).

She was very concentrated and silent throughout the drawing process, which took quite a long time, with meticulous colouring in. There were ways in which she used detailed planning and control to make her drawing more efficient (I will do a long time to draw all the sun… and then I used this one to do a little time) and she drew the bees in a 'factory line' approach of doing all the black stripes, then all the yellow stripes, then all the legs and wings. There was no evidence of her being distracted or sent off task at any stage and the impression of the final picture is that it was more-or-less exactly the picture she had in mind at the start.

Dave. Using distractions as ideas, but uniting the whole with logic and sense

Dave is something of an enigma. On the one hand he is seemingly very open to new stimuli and even distractible (I looked out of the window and then I heard a plane and that's why I drawed the plane); on the other he is quite rigid, focused and very obedient to the rules of reality (Do pigs live in sandy places? No!)

For a child of his age (6yo) he had prolonged focus on executing his drawing, taking nearly an hour, with no apparent boredom or fatigue ([Was there ever a bit where you felt a bit bored?] No)(piece by piece, box by box by box). He was very concerned with things making sense (I knew that I wasn't going to use that one because that doesn't really make any sense at all) which points towards straightforward, realistic representations, but he was simultaneously concerned with his creation being interesting (I wanted my picture not to be like really boring like a boring picture of a house that would be quite boring). This line sometimes proves a delicate one to tread (I would choose a boat because where could you fit a zigzag line into a picture?).

He showed some really nice examples of convergent creative thinking, bringing together different ideas into one new and valuable solution (I started to have an idea that it would be really hot that's why I was drawing the sweat on the camel) and used deliberate logic to solve problems (a house could be like on the edge of the desert because houses are sometimes like there's a tiny bit of desert so they're on like the very edge and then there's a town).

Divergent thinking came less naturally to him (I can't see how I could make anything, except pretend things out of that one), with no examples of coming up with multiple ideas from one stimulus and plenty of times where no ideas were forthcoming at all (And that one that was a hard one too). There was one moment, when asked to *try* to make a shape into something where, through physical manipulation, he had an insight moment of realizing that turning the shape upside down brought with it new possibilities (That's only pretend things I can make out of that one…unless I moved that piece around and I put it there that could be a leg and if I put four more it would be like the legs of an animal and that would make sense). But this strategic manipulation of input wasn't something he did naturally preferring ideas that came without effort (I chose that one because it looks exactly like a sun)

His creative preferences are grounded rather than flights of fancy (There's no such thing as a giant bird unless you've drawn it) (That's when it makes lots of ideas come when it makes sense). But within this constraint, he is open to stimuli which for others might be simple distractions and new ideas can fly in (Nearly every time you look outside there's birds in the sky so I think I'll draw a few birds).

Harriet. With self-awareness, openness and tricks, creativity can be taken in hand

Harriet is almost a self-help book on creativity. She combines openness (I like strange things) with confidence (usually I always just think of something) and a wise-beyond-her-years understanding of the accidental magic that can make something creative (if it ends up as something nice then I just stick it up on my wall and tell everyone I did it on purpose).

There are two distinct routes to creativity for her; one emanates from her openness to the new, the strange, the weird and her willingness to let go and be led by apparently random events unfolding (first it was trying to be a door…then it looked more like a window…then I realized I wanted to keep it like that because it looked weird). In this mode, she is quite willing to be led by her actions more than her thoughts (my brain kinda hadn't caught up with me). The second route is almost the exact antithesis. It is a deliberate set of strategies designed to maximize predefined creative output. The clearest example was her strategy for making her picture have a surprising and unexpected colour scheme (I wanted it to be strange colours…so sometimes I was just taking the nearest pen or a random pen to make it look like an unusual colour). It wouldn't be too much of a leap to say that each of these seems to illustrate one of each of the dual path prototypes.

Her ideation method is another exemplar of balancing the benefits of both focused and defocused thought. It is as if she makes a list of everything which might help come up with idea (all the books I've read which are a billion…different pictures that I've seen… the colours that were there…pictures that I've done before) and throws them all together like a creative primeval soup ready to recombine. She then has little tricks she uses to help keep the defocused thing just focused enough (holding a pencil makes my mind not wander off…it makes me think about drawing)

The final weapon in her armoury is a great level of patience and attention to elaboration (If I think about only the individual bits then I do more detail) as well as a metacognitive awareness of how to balance well enough to stay on track (I didn't want to smudge it so I kind of went slow…but also hurry up because it was getting very boring). I have described her as 'master of her universe'.

Betty. A detailed memory and deliberate switching between concentration and relaxation

Betty's creation was heavily based on a depiction from memory; the changes from the original (the Moana movie) were subtle (I wanted to change it a little bit). As a consequence, her account contained more explicit mention of memory (I might use the same ideas from the movie). Is it just chance that led her to this kind of picture? Lack of creative confidence? Or a different measure of creativity – she mentions a few times that she wants it 'similar but different' so maybe her idea of creating is to do with her own small tweaks to something else.

Another thing that stands out in her account is the switching between concentrating and deliberately switching off, relaxing, to enable thoughts to come (I realise I'm concentrating too hard and then that's normally when my mind goes blank... and then after I sit back and then I relax and then after it comes back to me). This could be as much to do with evoking memories as opening up to new ideas. We all know the feeling of failing to remember something we are trying hard to remember and then remembering it as soon as we cease trying. Perhaps she is speaking less of defocused ideation and more of defocused remembering: what, if anything, is the difference?

Her spontaneous ideation in the face of new stimuli (a hawk just popped into my head) showed evidence of thinking which was quite unusually creative and broad ranging. She saw things in the shapes which other children did not (witch’s hat as broken cot, birthday cake as drawing pin or playground roundabout), and rarely went for the most obvious choice. Her demeanour was in contrast to this freewheeling ideation; she was controlled, still, undistracted (despite plenty of noise and commotion) and calm. She said the only thing which would make it hard to have ideas would be multi-tasking.

There was a good deal of self-talk, mentions of liking the idea of doing something, ‘telling herself’ things, knowing her own limitations, a high degree of self-awareness, a level of humility and modesty. She dwelled upon the social aspect of creativity, both in terms of input (Sometimes I get ideas from other people) but also in output, other people ultimately often being the judge of the value of an idea (when other people think it’s bad…then I think it’s a bad idea).

Because she is concerned with specific memories, specific representations, does that mean she is less open to surprising creative possibilities (normally all the ideas are in my head and I just remember it)? Her way of being creative seems to be to find something in memory, in a high level of detail, as 'true' to the original as possible and then to deliberately decide on the extent to which she wants to change it from that original form to make it her own. A high level of detailed elaboration (it was kind of darkish light…loads of dark colours). In short, a very controlled process – control in the search, control in the change.

Kitty. Strong spontaneous associational abilities…until the obstructor steps in

Kitty is a counterpart to Harriet. They both show high levels of control and strict evaluation of their own work, but are differentiated by their degree of openness to new experience. Kitty does not like things which are weird or strange and is somewhat anxious about things which are unpredicted (I got off the line…it wasn't relaxing because i might have got it on my school top). Whilst in spontaneous ideation, she can provide rich, surprising, far associations (this could be a bank and it's all calm and then here was horses riding everywhere and robbers coming) and evocative poetic story-telling (I thought this could be a candle in the river like some people celebrate lights in the river and I thought that can be like a bridge and all trees coming over), when it comes to evaluation, the rules become more didactic (I didn't want it like that because it would just be weird), things need to follow logic rather than imagination (it would make a little bit more sense) and she gets cross when things go wrong (I felt just mad that I did that).

There is a clear sense of the battle between these two sides and a slightly melancholy impression that for her creativity is an impossible dream (it doesn't really look like a creative picture…I think I've just done a normal picture). At one point she did allow herself to loosen the constraints a little (splashes can go anywhere) and this was the one point in her picture where something seemed to arise from the gut – or from the hand (I love drawing this… I think my hand was going first) and resulted in a really good piece of detail. For the most part though, she prefers to stick to what she knows (it would be my first time drawing that and it might go horribly wrong), only try new things once they have been practiced and perfected (I need a little bit more practice to do it that way) and taking things nice and slow (I was making sure it was steady). Even small deviations from the plan are generally not acceptable (I was feeling mad because it's just a different colour and I like everything the same colour).

After the event, perhaps when the high level of control is turned down a bit, she can again see more creative possibilities (I was gonna do like a treasure chest and like sea horses and under sea creatures…and then I forgot; I could have changed the sea the colours of the sea and the mountains…but I didn't). Her understanding of what creativity comprises is comprehensive, like an idea recipe (I think it just pops up when you look at stuff, you see stuff and you just like combine it together and think how you're making it better I think the brain puts all that together and makes an idea). In practice, it seems that the effortful 'putting it all together' overrides the popping up; in her description of where things happen in her brain, creativity and concentration both happen at the front (they link at the front and they just park up in my head) with sometimes negative consequences (that's where it hurts if I concentrate too much).

Roxy. Careful modulation of focus, an abundance of ideas and a flexible approach to evaluation

Roxy's interview started off less than ideal as it transpired, too late, that she was wary of the cameras (Not really self-conscious but… just a bit… am I doing something wrong?). Consequently, she was keen to get her picture over with and completed it in just a few minutes. The interview focused more on the spark stimuli and I used some think aloud fragments to try to get to the heart of her creative process. This reaped rewards.

She had great awareness of her own creative process and provided potent validation of well documented creative processes. One was a most pleasing depiction of Wallas' four stages of creativity (I think of loads [preparation] and then… I step back [incubation] and there's still like this one glowering in my mind [illumination] and I just think yeah that one [insight]). Another was her realization and eloquent description of her own experience of functional fixity (Once I've kind of got one image in my mind… I kind of find it a bit harder to find a different one) as well as some textbook examples of how to overcome it (I just try and like… maybe swap parts of it or look at it from a different angle, or step back and see if I can see something else). Further sophistication in the creative metacognition vein came from an analogy between the angularity vs fluidity of the spark shapes and the fluidity and ease of prompting ideas (Cos it doesn't have as many like sharp points, it's easier to think of other ones [ideas]).

The simple addition of time improved not just the fluency but the originality of her ideas (when I first saw it I didn't really see it… yeah I can see it as, what's it called, those Christmas door wreaths or something? That you put on your door. Or also like a clown's thing that they put on their neck and then they have all those spikes coming out). But generally she was not someone short of ideas; if anything she was burdened by an excess of idea generation; particularly in the absence of constraint (my mind would have been a frenzy).

She talked about how increased constraint negatively affected evaluation but not generation (it doesn't make it harder to come up with them, it makes it harder to find the one that will work) suggesting the former is controlled while the latter is not. Further evidence of this came from her description of how enforced focus can disrupt spontaneous ideation (when you're made to look at a particular one, it's like harder). She also had a flexible, creative approach to evaluation, seeing it as an opening up rather than a closing down ([I chose it] because I thought you could relate more things to it).

Her creative process in a nutshell is thus: (Immediately like loads of ideas come to my mind, so then I try and like ‘Caaalm down’ and just find one that really captures me).

Chapter 5 appendices

Centre for Educational Neuroscience
University College London | Birkbeck University of London | UCL Institute of Education

Birkbeck UNIVERSITY OF LONDON

Executive functions and creativity
Head teacher information sheet

Researcher: Cathy Rogers cathyjanerogers01@gmail.com
Supervisor: Prof Michael Thomas ubjtc22@mail.bbk.ac.uk
Ethics number: Dept. of Psychological Sciences, Birkbeck, Ref. 181989

Dear Head teacher

We would like to invite pupils in your school to take part in a research project. This information sheet will explain the purpose of the study and tell you more about what would be involved on a practical level, so that you can decide whether or not to involve your school. The project has received ethical approval from both the Department of Psychological Sciences and the College Research Ethics Committees of Birkbeck, University of London. If you would like any further information, please do not hesitate to contact the researcher Cathy Rogers.

What is the study about?
The study is investigating the effect of training children's executive functions on their creativity. Executive functions are cognitive processes which govern our ability to stay on task, avoid being distracted and plan ahead. Better executive functions are associated with a range of benefits for children, both in the short term (eg better exam results) and in the longer term (eg better job prospects, better health, higher income).

This training, as well as hopefully bringing about improvements in children's executive functions themselves, might carry transferred effects to other aspects of learning – and in this study we are investigating the potential transferred effects to children's creativity. In particular, we are interested in how children's ability to inhibit or 'switch off' certain internal or external distractions might help or hinder their creative efforts.

The creative process has not been studied in great detail in primary school age children so we hope that this research will provide important new information about children's creative thinking and how it relates to their learning more generally. Once our research project is complete, we will communicate our results to educators and parents as well as to the wider public.

What are the practicalities?
The training would take place over a 6week period during the autumn term 2019 (ie between September and December) and within the normal school day (ie between 9am and 3pm). Teachers would be trained to use a simple set of materials (cards, board games and whole class games) which have been specially developed to train children's executive functions and which have proven effective in previous studies. The training

would involve half hour sessions, carried out two or three times a week over the 6 week period (ie 12-18 sessions in total). All the training would be carried out by the children's normal teacher(s) at a time (eg morning, afternoon) which best suits the class and all children in the class can take part in the training. We are looking to recruit children in years 4 and 5.

This trial is a randomised controlled trial. This means that participating classes would be randomly assigned to the training intervention or to an active control condition; in the control condition, children would also play card and board games but these would be focused on numeracy (eg snakes and ladders) or literacy (eg Scrabble) rather than executive functions.

In addition to the training, children would be tested before and after the training on a range of short tests of executive function and creativity. This is in order to measure whether – and the extent to which - the training has brought about changes in these measures. The testing would be done within the normal school day with groups of 6-8 children at a time and would take approximately 30 minutes per group. Since some tests are on computer, this testing would require use of the school's IT facilities. These tests would be done on 3 occasions: in the 2 weeks prior to the training programme, in the 2 weeks immediately after the training programme and finally 6 weeks after that.

The testing would be carried out by trained researcher Cathy Rogers, a PhD student at Birkbeck, University of London. All the tests have been specially developed for children, and involve a mix of simple pen and paper tests and short computer tests. Children typically find the tests fun and enjoyable to do. They are encouraged to have fun, be playful in their answers and use their imaginations. They do not receive individual feedback on how they have performed.

The children will also complete a short questionnaire which asks them about how often they engage in creative activities (drawing, making up stories etc) at home. Finally, we would also ask you for participating children's average grades in English and Mathematics, so that we can look at their creativity in the context of their overall learning.

What will happen to the data?
The data will be completely anonymised. Each child will be assigned a code, and only this code will be used in the computer for analyses. The correspondence between the code and the name of the child will not be given to anyone outside of the research team. Results will be used as part of Cathy Rogers' doctoral thesis. In the thesis or any potential publication or conference report, group averages will be reported rather than individual scores and schools will not be named.

How do we take part?
If you agree for your school to take part in our study, we will prepare information packs for parents/carers and children and discuss the process for seeking consent. We will

come and see you to explain the study in detail, show you the training materials and make a detailed schedule.

Does the school get anything in return?
There are various benefits to your school in taking part in this research. Firstly, in intervention groups, the research would provide a short, free training designed to improve executive functions. For those assigned to control groups, we would be happy, once the study is complete, to share the materials used in the intervention so that teachers could use them if they wished. We would also be happy to come to your school and run a workshop or assembly to talk to children about their brains and how they work. We will also be pleased to present the results of our study to you and interested staff and parents, once the data has been analysed. More broadly, your school would be contributing to an important research area with a world centre of excellence in psychological research.

We very much hope that this research will be something you would like to be involved with and look forward to hearing from you.

Yours sincerely,

Cathy Rogers
PhD researcher
Centre for Educational Neuroscience
Birkbeck, University of London

If you have any questions, please do not hesitate to contact the researcher, Cathy Rogers cathyjanerogers01@gmail.com Tel 07969 123201. You can also talk directly to the supervisor of the project, Professor Michael Thomas ubjtc22@mail.bbk.ac.uk

What makes children creative?
Parent/carer information sheet

Researcher: Cathy Rogers croger05@mail.bbk.ac.uk
Supervisor: Prof Michael Thomas ubjtc22@mail.bbk.ac.uk
Ethics number: Dept. of Psychological Sciences, Birkbeck. Ref. 181989

Dear Parents / Carers

We would like to invite your child to take part in a research project. This information sheet will tell you the purpose of the study and give you details about what is involved, so that you can voluntarily choose whether or not to let your child take part. Declining to participate will not disadvantage you or your child in any way. If you would like any further information, please do not hesitate to contact the researcher Cathy Rogers croger05@mail.bbk.ac.uk

What is the study about?
The study is investigating the process of creativity in children. We are trying to find out more about what encourages or discourages children's creativity. In particular, we are interested in how children's ability to concentrate, focus and 'switch off' distractions might help or hinder their creative efforts.

The creative process has not been studied in great detail in primary school age children so we hope that this research will provide important new information about children's creative thinking, with potential implications for early years' educators, parents and the wider public.

Why has my child been chosen?
Your child's school has agreed to take part in this project. This information sheet has therefore been sent to all children in years 4 and 5. If you give your consent, we will also explain the purpose of the study to your child and double check that s/he is happy and willing to participate before we start our research.

What would my child have to do?
There are two parts to the study. The training part will help children develop their skills of paying attention, concentrating and planning ahead. It will take place as part of your child's normal lessons, and be carried out by their usual teacher. Your child, along with the whole class or in small groups, will play a variety of specially-developed card and board games. They will do this a few times a week for 6-8 weeks for about half an hour at a time.

The second part, the test part, will also take part in the normal school day and this time will be carried out by trained researcher Cathy Rogers, a PhD student at Birkbeck, University of London. Your child will complete various pen and paper tests, some where they have to give short written answers and some where they do drawings. The tests are presented as games and the children are encouraged to have fun and be playful in their thinking. It will be emphasised to the children that there are no wrong answers. Your child will also be asked to play some simple games on a computer – for example identifying a particular animal or shape and pressing a key in response. At the beginning of each session, each task will be fully explained to your child and they will be able to ask any questions they have. They will be told that they can stop participating in the study at any time, without having to give a reason. Cathy will be present with them for the whole testing session.

There will be three testing sessions, one before and two after the training part of the study. Each session will last for approximately 30 minutes.

We will also ask your child's teacher for your child's average grades in English and Maths, so that we can look at their creativity in the context of their overall learning.

What will happen to the data from my child?
We are interested in finding out how children perform *on average* rather than looking at the results of any individual child. The data will be completely anonymised. Each child will be assigned a code, and only this code will be used in the computer for analyses. The correspondence between the code and the name of your child will not be given to anyone outside of the research team. Results will be used as part of Cathy Rogers' doctoral thesis.

Your child's involvement in the study will remain confidential except in the highly unlikely event that the researcher has a serious concern regarding a child protection issue. All data will be collected and stored in accordance with the Data Protection Act 2018. The project has received ethical approval from both the Dept of Psychological Sciences and the College Research Ethics Committees of Birkbeck, University of London.

How do I give my consent for my child to take part?
If you agree that your child can take part in our study, please sign the attached consent form. Please return this form to your child's teacher, who will pass it on to the researcher. Even after signing the consent form, you are still free to withdraw your child from the study at any time and without giving a reason.

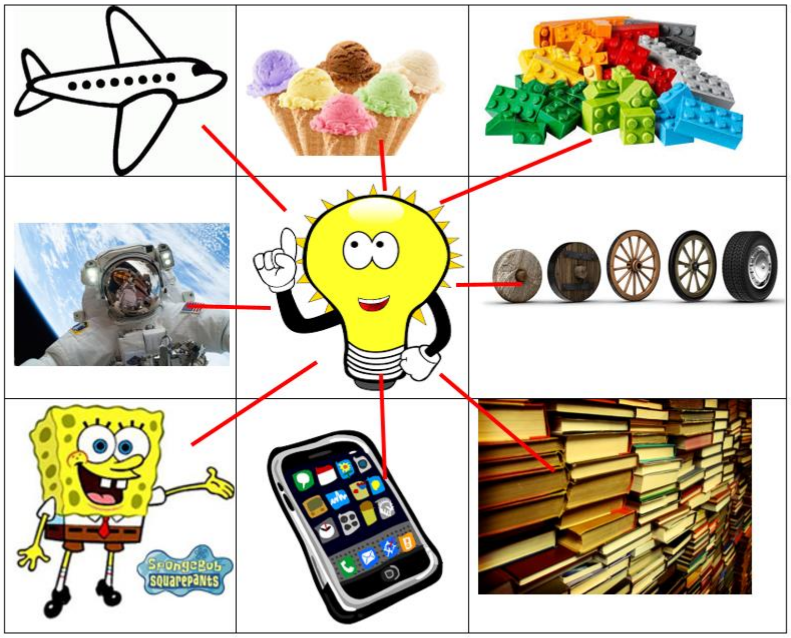
We are extremely grateful for the time you and your child have given us.

If you have any questions, please do not hesitate to contact the researcher:
Cathy Rogers croger05@mail.bbk.ac.uk Tel 07969 123201

You can also talk directly to the supervisor of the project: Professor Michael Thomas ubjtc22@mail.bbk.ac.uk

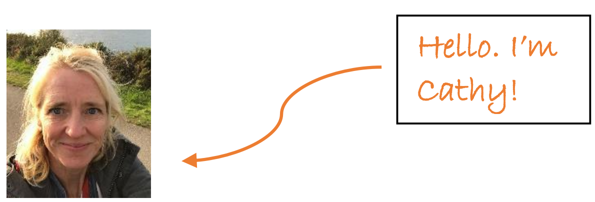
What helps children to be creative?
Information sheet for children

What is creativity and why should we care about it?
'Creativity' means coming up with good new ideas. Without creativity, humans might still be living in caves and eating horrible leaves! Think of all the things that have been invented since then….



What does that have to do with me?
We would like to understand more about what helps children to be creative. To do this, a researcher called Cathy Rogers will visit your school to work with you and your teachers. You will be allowed to leave your classroom to play some games on a computer, do some drawings and also try to come up with some new ideas – Cathy will explain each game as you do it. You will be able to ask Cathy any questions you have about anything you're doing and we hope you will really enjoy the games.

If you are happy to take part, you can just tell Cathy. If you change your mind and decide you don't want to do it, that's fine too. The information we collect about you will not be given to anyone else and your name will never be used in any of the research.



If you have any questions, you can email Cathy: croger05@mail.bbk.ac.uk

‘Nelly and Noah in the Rainforest’ training intervention

Instructions for Teachers

1. Structure and support principles

There are 5 small group games and 5 individual worksheets for children to complete by themselves. The planned timetable means a maximum of two small group games and one type of individual exercise need be learned each week. All the activities are framed within the general setting of a rainforest and the adventures of the two explorers, Nelly and Noah.

There are some key principles important to bear in mind for successful training:

1. Give clear introductions to the games and sufficient practice time.

When introducing a new game, all cards which will be used at that level should be shown and explained. Children should 'mirror back' names of animals, plants etc to make sure all children are familiar with all pictured items.

The words in the introduction to each game can be read out as they are to give the context for the game. Other italicized words are also meant to be read out loud.

All children should start at the simplest level of the game

It is important that less able children have sufficient practice time at lower levels before moving up.

At first the games should be carried out at a slow and controlled pace. Games shouldn't be made into a race until everyone playing has mastered the rules.

2. Ensure a steadily increasing level of difficulty.

All activities have multiple difficulty levels, shown by magnifying glass icons (1 is the easiest, 3 is the hardest).

A switch to the next level should only be made once children have mastered the previous one.

Executive functions come into play through activities being somewhat demanding so it is important to encourage children to continue playing even if they have some difficulty – and to carry on until they can manage to play the games.

If a higher difficulty level is too challenging for one or more children in a group, teachers should ideally go back and repeat the last, less challenging game level.

It is important that all children are given sufficient practice to allow mastery of at least two levels of difficulty per game.

3. Regularly change roles.

As well as improving their executive functions through playing, children benefit from supervising.

In the small group games, children should take over and lead the games, identifying and correcting mistakes. For individual activities, solution sheets are given for children to correct themselves.

Small groups should initially be comprised of children with reasonably similar levels of competence. Children should not be too over- or under- challenged.

The small groups should be changed frequently - in every session they should be composed differently

Allow children to self-manage, resolve conflict, work out their own strategies, rather than intervening to help (as much as possible)

The individual worksheets can be used at your discretion (ie in addition to using them as scheduled) if children aren't getting enough practice in group games, groups are too big, for children who come into class late and so on.

Table 1 shows the recommended six-week-programme.

	Session 1	**Session 2**	**Session 3**
Week 1	Cheeky monkey Collecting insects	Cheeky monkey Collecting insects	Cheeky monkey Identifying animals (ind)
Week 2	Leafcutter ants Medicine woman	Leafcutter ants Medicine woman	Leafcutter ants Looking for food (ind)
Week 3	Day or night Collecting insects	Day or night Medicine woman	Day or night Labyrinth in the rainforest (ind)
Week 4	Cheeky monkey Medicine woman	Leafcutter ants Day or night	Collecting insects Drawing lessons (ind)
Week 5	Collecting insects Day or night	Cheeky monkey Leafcutter ants	Medicine woman Changes in the rainforest (ind)
Week 6	Day or night Leafcutter ants	Medicine woman Collecting insects	Cheeky monkey Hardest levels of any individual games (ind)

Lesson plan

The general structure of lessons, assuming a class size of 24-30 children, should be as follows:

1. The class should be divided in half, the class teacher taking one half and the teaching assistant (or other helper) the other. One half will play game A for the first half of the lesson, the other half will play game B. After 15 minutes, they swap over. So in week 1, session 1, teacher would start with *Cheeky monkey* and TA would start with *Collecting insects.* After 15 minutes they would swap games.
2. Children should be organized into groups of 4 (max 5), seated around small tables so that they can all see each other. This should make 3 groups per half class.
3. It is important that the groups should be mixed up and changed around each lesson, so that children experience the games with different players. Children who are not placed within groups for any reason can complete individual worksheets
4. Once the game has been explained to the children, one child in each group should be assigned the 'manager' of that game. That child will be responsible for running the game in that group, making sure the game is being played correctly. Children should take it in turns to play this manager role.
5. The teacher/TA should move around the class, watching each of the groups, to make sure that games and particularly the right levels of the games, are being played.
6. It is important that children don't race ahead too quickly, but instead play at a level until everyone is competent at playing the game and can move up to the next one.
7. Clearly, the first session in a week when children are learning new games, will be more taken up with explaining. By session 2, it should be possible for children to immediately start playing the game as soon as the lesson begins.
8. At the end of the lesson, it is worth taking a moment to sort all the cards and games so that they are ready to play next time.

2. Small-Group Games

2.1 Cheeky Monkey

Material

- 16 playing cards with green background
- 16 playing cards with red background
- 5 control cards (tree house cards with all items pictured)

Introduction

Nelly and Noah live in a lovely jungle tree house. A monkey family lives in the same tree. The smallest monkey is very cheeky. When Nelly and Noah leave in the morning, the monkey climbs into their tree house and rifles through their things. When Nelly and Noah return home in the evening, there is always something missing.

Help Nelly and Noah figure out what the monkey has taken

Game structure

Each child is given a control card (one of the large cards) which shows eight objects lit up by a spotlight. *Here you can see Nelly and Noah's tree house. Eight objects are lit up.* Point to each object (torch, socks, shoe, camera, flask, magnifying glass, lantern, book) to ensure everyone playing is familiar with the objects. *The cheeky monkey always steals one of these objects.* Show a green playing card and explain: *Here you can see the objects again. But there is one object missing – that's the one the monkey has taken away. Can you figure out which object is missing?*

Variant I (familiarization)

Green cards only. Not a race. Turn over a green card and instruct children to work out which item the monkey has stolen. Children should indicate by a hand signal when they have the answer - but no one should say it out loud until everyone has got it.

Variant II

Green cards only. Cards are put in a pile so that everyone can reach. One card at a time is turned over and it is a race to find the missing object. The first to spot it wins that card. The child with the most cards wins the game.

Variant III

Red cards only. Here, additional objects complicate the search for the missing object. But the monkey still only steals items which are lit up. Rules as for variant II

Variant IV

Red and green cards can be mixed together.

Variant V

Can be played with only green or only red or a mix. But here the control cards are taken away so children need to remember the lit up objects by heart.

2.2 Collecting insects

Material

- 55 insect cards: fly, wasp, mosquito, ant, beetle
- 1 jam card
- 5 spider cards (3 red spiders, 2 black spiders)
- 5 snake cards (3 active snakes, 2 snakes sleeping)
- 2 rule cards (1 Animal, 1 Number)

Introduction

Nelly and Noah want to inspect every type of insect in the rainforest. They attract insects with the smell of ripe fruit, then when enough insects have settled in one place, they trap them in a jam-jar.

Help Nelly and Noah collect all the insects

Game rules

All cards are shuffled and dealt out. Each child puts their cards face down on the table (the draw pile). The jam jar card is placed in the middle so everyone can reach it. When a signal is given (e.g. 'Ready steady GO') every child turns over their top card and puts it face up in a new pile in front of them (the discard pile). The top cards of the discard piles need to be easily visible to everyone playing.

When two cards match according to the relevant rule (ie 'A*nimal'*, 'N*umber'* or 'A*dd up to 8'*), it is a race for the players to spot the match and tap the jam jar card as quickly as possible. Whoever comes first, takes all the discard pile cards (including their own) and puts them at the bottom of their draw pile. If someone taps the jam jar by mistake, the discard pile of that player is distributed evenly to the other players. The game is won by whoever wins all the cards – or who has the most cards when the game stops.

Variant I: Animal or number?

Snake and spider cards are left out. Children should be familiarised with the different insect cards by pointing to and naming each of the different insects. Then the rules A*nimal* and *Number* should be introduced: *We will first play the animal game. You need to tap the jam jar card as soon as you spot a match of two insects of the same type; it doesn't matter how many are on each card. Once* children understand the Animal rule, rule type *Number* should be introduced: *Now we'll play the Number game. You need to tap the jam jar card as soon as you spot a match of the number of insects; it doesn't matter what type they are.*

To begin with, it is advisable to let children play according to just one rule. When they have understood the game, the two rules can be combined. So the game might start off with the A*nimal* matching rule then, during the course of the game, the support person can initiate a rule change by changing the rule card from A*nimal* to N*umber*.

Variant II

Spider and snake cards are added. Spider cards (red and black) should be introduced: *Watch out for the red spider, it's poisonous! When someone turns over a red spider, call out "Spider!" as fast as you can. Whoever calls out first, will get one card from each of the other players' draw piles. But be careful because the black spider is **not** poisonous. If someone turns it over, you should just carry on playing.* If "S*pider!"* is called out by mistake, whoever calls it must hand over a card from their draw pile to the other players.

The snake cards (active and sleeping) should also be introduced: *Snakes can be dangerous too. When someone turns over a snake card, you need to clap your hands to scare the snake away. Whoever claps first, will get one card each from the other players' draw piles. But be careful: if the snake is curled up, it is asleep and is not dangerous. If someone turns it over, just continue playing.* If someone claps their hands by mistake, they must hand over a card from their draw pile to the other players.

When the children have understood and used all the rules, they (as well as the support person) can swap the rule cards over themselves – ie to change 'Animal' to 'Number' or vice versa.

Variant III: EXACTLY 8

The rule cards Animal and Number should be set aside. At first, snake and spider cards should also be omitted but then introduced once early stages are mastered.

This game should be introduced: *With rule type "Exactly 8" you need to tap the jam jar as soon as you count exactly eight insects of the same type. Be careful because there are different possible combinations.* Give examples of some possible combinations using the cards eg, 1+1+2+2+2, 1+1+1+2+3 etc

If anyone makes a mistake, they must hand out their discard pile cards evenly to the other players. As soon as the children are familiar with the game, spider and snake cards can be added in. If a child has turned over all their cards but still has cards in their discard pile, they can continue playing to look for a match of 8. If they are not the first to spot one, then they will be out of the game.

Variant IV

To make any variant even harder, the rule card (ie 'Animal' or 'Number') can be covered up, so that children need to remember the relevant rule. A change of rule is only indicated verbally.

2.3 Leafcutter ants

Material

- 18 regular playing cards (circle, triangle, square in green, yellow and red)
- 5 playing cards of “unusual colour” (blue, rose, purple)
- 5 playing cards of “unusual shape” (oval, diamond, rectangle)
- 6 cards “butterfly” (leaf pieces plus butterfly in the corner)
- 1 leafcutter ant card (stop card)
- 1 target card (3 columns headed with green square, red triangle, yellow circle)
- 8 control cards (A1 through to D2)

Introduction

Leafcutter ants have very sharp jaws. They bite leaves into different shaped pieces before gobbling them up. Nelly and Noah find this fascinating and observe the little ants, making notes of the most common colours and shapes of the leaves. When Nelly and Noah find leaf pieces, they sort them according to their colour and shape.

Help Nelly and Noah sort out the leaf pieces

Game structure

All the different cards should be shown, and all the colours and shapes named. Particular attention should be drawn to the unusual colours and shapes as these are quite hard to spot. One of the children manages the game and holds the control cards (A1 to D2) as well as the leafcutter ant card. The target card lies on the table facing the players. The players, taking turns, have to accurately sort the cards according to the relevant rule (colour or shape), placing them onto the target card as quickly as possible. The manager checks the cards have been correctly assigned (using the control cards to check). If a card is put down incorrectly, the manager puts down the stop card (the leafcutter ant) to signal the player to correct it.

For each level of difficulty there is one colour control card and one shape control card. Colour always comes first. Ie A1, B1, C1 and D1 are ‘sort by colour’ and A2, B2, C2, D2 are ‘sort by shape’. After each round, the cards should be shuffled and the change in sort rule explained. The manager role should also be swapped each time a level is completed so that all children get a turn playing and managing.

Variant I (Control cards A1 and A2)

Cards of “unusual colour” (blue, rose, purple), “unusual shape” (oval, diamond, rectangle) and “butterfly” cards are set aside. All the other cards are shuffled and given to the first player who must sort them either by colour or shape, depending on the control card rule. A1 signals ‘sort by colour’. A2 is ‘sort by shape’.

Variant II (Control cards B1 and B2)

“Butterfly” cards are set aside. Cards of “unusual colour” and “unusual shape” are introduced: *Nelly and Noah sometimes find rare leaf pieces. They haven’t noted them in their explorer’s book, so they need to be put aside when the cards are sorted. Some leaf pieces have unusual* ***colours****, so when we’re sorting by colour, we put them aside.*

But when we're sorting by shape, they should be sorted along with the normal cards. There are other leaf pieces with unusual ***shapes****, so when sorting by shape, we need to put them aside. But when we're sorting by colour, they should be sorted along with the normal cards.* B1 signals 'sort by colour'. B2 is 'sort by shape'.

Variant III (Control cards C1 and C2)

Cards of "unusual colour" and "unusual shape" are set aside. "Butterfly" cards are introduced: *You need to be very careful with cards showing a butterfly, because Nelly and Noah made up a game with them – when there's a butterfly, the sorting rule swaps over. So when you are sorting cards by colour, you need to sort cards showing a butterfly by shape instead. And when you're sorting by shape, you need to sort cards with a butterfly by colour. All the other cards, without a butterfly, are sorted by the original sorting rule.* C1 signals 'sort by colour'. C2 is 'sort by shape'.

Variant IV (Control cards D1 und D2)

The complete set of cards is now used. Depending on the sorting rule (colour or shape), *unusual* colours or *unusual* shapes need to be put aside when sorting. For "butterfly" cards, the change in sorting rule always applies. D1 signals 'sort by colour'. D2 is 'sort by shape'.

2.4 Medicine woman

Material

- 12 instruction cards with three rows on each (1 row=1 round; cards A1 through to F2)
- 7 animal cards (monkey, sloth, tree squirrel, snake, lizard, parrot, toucan)
- 1 target card (Nelly and Noah carrying the box back to the forest)
- 1 card «medicine woman»

Introduction

Nelly and Noah have an important mission. With the help of the medicine woman, they need to check if the rainforest animals are healthy by examining each one. When the examination is done, Nelly and Noah bring the animals back to the forest in a big wooden crate - except for the birds, who can fly back by themselves. Sometimes, the medicine woman notices an injury; in that case the animal needs to stay with the medicine woman to be looked after.

Help Nelly and Noah bring the right animals back to the forest

Game structure

Before playing, point to the seven animal cards (monkey, sloth, tree squirrel, snake, lizard, parrot and toucan) and jointly name them with the children. One child manages the game while another plays. Manager and player roles should be played by all children in the group. The card showing Nelly and Noah carrying the box and the medicine woman card are put on the table facing the players.

The child playing first is given all seven animal cards. The child managing the game holds the instruction cards (A1 first, all the way to F2). Each card shows three rounds of the game (one row=one game). On the left of the card are the animals to be read out by the manager and the right side acts as a check for which animals should be brought back in the box. To start the game, the game manager says out loud the animals which are either being sent back to the forest or which are ill. On a signal (‘Go’) the child playing can then start carrying out orders, namely, putting the cards of those animals which are being sent back to the forest on top of the target card. The game manager watches to make sure the correct cards are placed on the target card.

Each child should have a turn working through the cards of each level (eg level A) before passing on to the next child. The manager should also swap roles so that they get a turn playing.

Variant I (Instruction cards A1 and A2)

Nelly and Noah bring two animals back to the forest in each round. Point to the left hand side of the instruction card and explain: *This tree stands for the forest so animals shown on this card can be taken back to the forest.* Point to the right hand side of the instruction card and explain: *Here you can see the animals that Nelly and Noah have to bring back to the forest.* The game manager names the animals that are allowed back and says ‘go’. The child playing places the relevant animals on the target card.

Variant II (Instruction cards B1 and B2)

Now Nelly and Noah always bring *three* animals back to the forest. The game manager names the animals that are allowed back and says ‘go’. Then, the child playing places all the named animals on the target card. The game manager checks each time.

Variant III (Instruction cards C1 and C2)

Point to the left hand side of the instruction card and explain: *The tree shows which animals are allowed back to the forest – but the parrot and the toucan can fly back by themselves. They don’t have to be brought back by Nelly and Noah in the box. So the birds never get placed on the card with Nelly and Noah’s box.*

The person managing the game names the animals that are allowed back to the forest and says ‘go’. The child playing places all the named animals on the target card, except for the parrot and the toucan. Those cards should instead be placed directly in front of the player. The game manager checks the cards have all been correctly placed.

Variant IV (Instruction cards D1 and D2)

Point to the left hand side of the instruction card and explain: *While examining all seven animals, the medicine woman realises that two animals are injured. The First Aid kit shows which ones are injured and have to stay with the medicine woman. Nelly and Noah can only bring back the other animals. The parrot and the toucan can still fly back, so they don’t need to go in the box.*

The game manager names the animals that are injured and says ‘go’. The child playing places all the animals (except for the parrot and the toucan) that were *not* named on the target card.

Variant V (Instruction cards E1 and E2)

Point to the left hand side of the instruction card and explain: Now *three of the animals are injured. They need to be taken care of so only the remaining ones can be brought back to the forest. The parrot and the toucan still fly back by themselves.*

The game manager names the animals that are injured and says ‘go’. The child playing places all the animals that were *not* named on the target card except for the parrot and the toucan.

Variant VI (Instruction cards F1 and F2)

The different types of tasks (ie back to forest and medicine woman treated) are now mixed. The symbol for each round tells the game manager which rule to announce.

If the tree is shown, the game manager will say: *The following animals are allowed back to the forest.* The child playing places all the animals named on the target card (except for the parrot and the toucan).

If the First Aid Kit is shown, the game manager will say: *The following animals are injured.* The child places all the animal cards that have *not* been named on the target card (except for the parrot and the toucan).

2.5 Day or night

Material

▪ 1 overview card with nocturnal animals (otter, jaguar, snake, monkey), plants and fruit (flower, tree, orange, melon)
▪ 24 playing cards with blue borders
▪ 24 playing cards with yellow borders
▪ 4 change-of-weather cards (sun/storm: signal rule change)

Introduction

There is plenty to explore in the rainforest, both day and night. During the day, Nelly and Noah get to inspect all the plants, flowers and fruits. But it's also very exciting to spend time in the rainforest at night when many of the forest animals are out and about. To make sure they see everything, Nelly and Noah sometimes sleep during the day and go out at night time.

Can you figure out if it's day or night so Nelly and Noah know what to search for?

Game structure

All playing cards show one plant and one animal. For cards with *blue* (night) borders, players need to name the *animal* shown. For cards with *yellow* (day) borders, they need to name the *plant or fruit*. Before starting the game, read aloud the names of all animals and plants on the overview card, to ensure all children are familiar with them. Blue and yellow borders should also be shown and explained. The change-of-weather cards (sun/storm) indicate a change of rule (storm clouds make the day dark, while lightening brightens up the night) i.e. the border colour matching rule swaps over. Now yellow borders mean naming the *animal*, and blue borders, naming the *plant*. These cards are only in variant three.

Variant I

Change of weather cards are left out. One child at a time takes a card from the stack (all the cards) and names the animal or fruit according to the border rule. If they are right, they keep the card. If they are wrong, the card goes to the bottom of the pile. The game is won by whoever has the most cards at the end.

Variant II

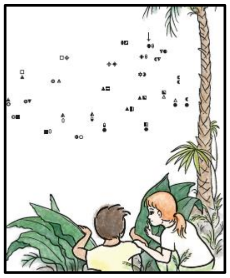
Change of weather cards are left out. All the cards are dealt out. The first child turns over a card so everyone can see; that child acts as a referee and can't answer this go (though they must work out the right answer in their head). The other children try to name the plant / animal as quickly as possible. The referee hands the card to whoever gives the right answer fastest. If no one gets it right, the referee keeps the card. If there is a tie, the card goes in the middle and will be won by whoever wins the next round. Whoever has the most cards at the end is the winner.

Variant III

Can be played with both variants one and two (ie individual players or as a race). The change-of-weather cards are introduced: *The weather can change quickly in the* *rainforest. When a storm comes up, yellow lightening brightens the sky. In these conditions, the yellow borders indicate night and you need to name the nocturnal animals. The day, on the other hand, gets dark, so now blue borders stand for day and you have to name plants. The change of rule lasts until the weather turns nice again, that is, until the next change-of-weather-card is turned over.*

3. Individual games

3.1 Identifying animals (dotty dot-to-dot)



Material
- ▪ 10 exercise sheets
- ▪ 10 solution sheets

Can you figure out what kind of animal is hiding behind the bushes?

Game structure
Matching symbols need to be connected in order to reveal an animal. It's trickier than a normal dot-to-dot because there are no numbers, just symbols which have to be joined together. The start symbol is always marked with an arrow. Its matching symbol then needs to be found – eg if the start symbol is a black dot, children need to look for another black dot and join the two black dots with a line. Each symbol also has a partner next to it - this shows the next symbol to look for and connect. Eg If the black dot's partner is a black triangle, children need to find another black triangle and connect them - and so on. When the puzzle is completed, an animal is revealed. The name of the animal should be written at the bottom of the sheet.

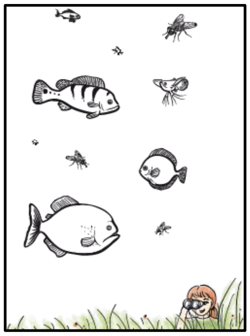
Exercise sheets have three different levels of difficulty:

√ The symbols are clearly distinguishable. There are few distracting symbols.

√√ Different symbols either closely resemble each other, or there are many additional, distracting symbols.

√√√ Different symbols strongly resemble each other and there are also many additional, distracting symbols.

3.2 Looking for food



Material

- 15 exercise sheets
- 15 solution sheets

Introduction

Nelly and Noah have been researching what rainforest animals eat. As they study the animals, they realise that the biggest animals always eat the biggest food, while the smaller animals go for the smaller food.

Can you match each animal to the right food?

Game structure

Each animal needs to be connected with the food that fits its size. Children must draw a line to connect the animal-food pairs, starting with the smallest and ending up at the biggest. So the smallest animal connects with the smallest type of food, then the line goes on to the second smallest animal and the second smallest food type and so on, right up to the biggest.

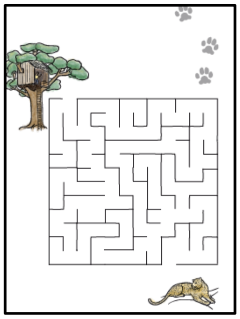
Exercise sheets have three different levels of difficulty:

√ Pictures show five of the same kind of animal in different sizes, as well as five foods in different sizes.

√√ To make it harder to establish the animals' size, some are partially hidden behind bushes or rocks.

√√√ Again, some animals are partially hidden. Additionally, animals or plants of different kinds are also included as distractions. These distractions should not be included in the continuous drawn line.

3.3 Rainforest mazes



Material

- 10 exercise sheets
- 10 solution sheets

Introduction

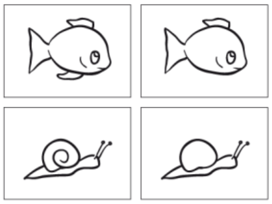
The rainforest is home to the jaguar, a very fast wild cat which can be very dangerous if it's disturbed while sleeping or out hunting. It's a beautiful animal and Nelly and Noah would love to see it in real life. But there are loads of different pathways in the forest so it's easy to get lost. Before heading out, Nelly and Noah plan their route on a map.

Draw in the path that Nelly and Noah should follow to reach the jaguar

Game structure

Children must find their way from the starting point (marked with a tree house) to the finish (marked with the jaguar). There is only one correct solution. If possible, the lines should be drawn without mistakes and detours, which will mean a bit of planning. The pen shouldn't be lifted off the paper while marking the route. The level of difficulty is steadily increased by the growing size of the maze and the greater number of dead ends.

3.4 Drawing lessons



Material

- 5 exercise sheets of *picture-pairs*
- 5 exercise sheets of *something is missing*
- 10 solution sheets

Introduction

Nelly and Noah are not the only children in the rainforest. There are several villages which are home to aboriginal families. The aboriginal children know everything about the rainforest and they're teaching Nelly and Noah how to draw everything accurately by letting Nelly and Noah copy their drawings. When Nelly and Noah finish a drawing, they give it to one of the children to check. The drawings are pretty good, but there is always something missing. Together with Nelly and Noah, the children complete the missing parts.

Now it's up to you to help correct and complete Nelly and Noah's drawings

Game structure

This game includes two different types of exercise sheets, five for every level of difficulty.

***Picture pairs*:** Four picture pairs are shown. The one on the left is the original and serves as a reference. The one on the right has between 1 and 3 elements missing. The pictures must be compared, then completed with the missing elements to make them identical.

Something is missing: The reference picture is shown above the line at the top of the page. The pictures below the line are each missing one element. Children need to complete each picture by referring to the picture at the top.

3.5 Changes in the rainforest (spot the difference)

Material

- 10 exercise sheets
- 10 solution sheets

Introduction

The rainforest is constantly changing. New trees and plants grow up and others are knocked down by storms; animals that are awake and active in the day disappear at night to sleep. Nelly and Noah want to keep track of the changes. They take photos of specific places and then take a second set of photos when they pass the same place again. Whenever they have two shots of the same place, they stick them in their book, right underneath each other and mark everything that has changed. Sometimes the changes are obvious and easy to notice. But often, they have to look very closely to make them out.

Help Nelly and Noah mark the changes to the pictures

Game structure

For this game, two very similar pictures have to be compared. In each one, seven to ten elements do not match exactly and need to be marked on the bottom picture. Children who finish quickly can be given a further challenge to reproduce the picture by themselves.

Exercise sheets come in three different levels of difficulty:

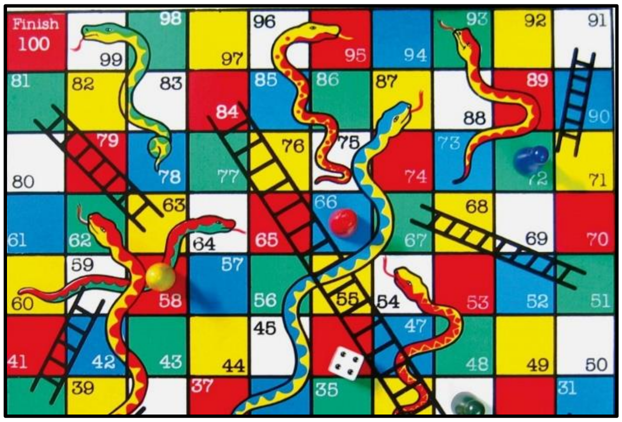
√ Drawings are clear and not very detailed. The seven differences are fairly big and obvious.

√√ Drawings have more detail. The seven differences are smaller and less obvious.

√√√ Drawings are full of detail. The ten differences are small and not very obvious.

Traditional games training intervention

Instructions for Teachers



1. Structure and support principles

There are 5 small group games and 5 individual worksheets for children to complete by themselves. The planned timetable means a maximum of two small group games and one type of individual exercise need be learned each week. Many of the games are likely already to be familiar to the children

There are some key principles important to bear in mind for successful training:

1. Give clear introductions to the games and sufficient practice time.

When introducing a new game, all materials should be shown and explained.

It is important that less able children have sufficient practice time at lower levels before moving up.

At first the games should be carried out at a slow and controlled pace. Games shouldn't be made into a race until everyone playing has mastered the rules.

2. Ensure a steadily increasing level of difficulty.

All activities have a range of difficulty levels; children should always start at the simplest.

A switch to the next level should only be made once children have mastered the previous one.

If a higher difficulty level is too challenging for one or more children in a group, teachers should ideally go back and repeat the last, less challenging game level.

It is important that all children are given sufficient practice to allow mastery of at least two levels of difficulty per game.

3. Regularly change roles.

Once children have learned the games they should, in their small groups, be able to take over and lead the games themselves, identifying and correcting mistakes and resolving disagreements.

For individual activities, solution sheets are given for children to correct themselves.

Small groups should initially be comprised of children with reasonably similar levels of competence. Children should not be too over- or under- challenged.

The small groups should be changed frequently - in every session they should be composed differently

Allow children to self-manage, resolve conflict, work out their own strategies, rather than intervening to help (as much as possible)

The individual worksheets can be used at your discretion (ie in addition to using them as scheduled) if children aren't getting enough practice in group games, groups are too big, for children who come into class late and so on.

Table 1: Training Schedule for 6-Week-Intervention

	Session 1	**Session 2**	**Session 3**
Week 1	Snakes and ladders Uno	Snakes and ladders Uno	Snakes and ladders Individual: dot-to-dots
Week 2	Brainbox Scrabble	Brainbox Scrabble	Brainbox Individual: word search
Week 3	Rummikub Uno	Rummikub Scrabble	Rummikub Individual: crosswords
Week 4	Snakes and ladders Scrabble	Brainbox Rummikub	Uno Individual: mazes
Week 5	Uno Rummikub	Snakes and ladders Brainbox	Scrabble Individual: sudoku
Week 6	Rummikub Brainbox	Scrabble Uno	Snakes and ladders Any individual games

Lesson plan

The general structure of lessons, assuming a class size of 24-30 children, should be as follows:

1. The class should be divided in half, the class teacher taking one half and the teaching assistant (or other helper) the other. One half will play game A for the first half of the lesson, the other half will play game B. After 15 minutes, they swap over. So in week 1, session 1, teacher would start with *Snakes and ladders* and TA would start with *Uno.* After 15 minutes they would swap games.
2. Children should be organized into groups of 4 or 5, seated around small tables so that they can all see each other. This should make 3 groups per half class.
3. It is important that the groups should be mixed up and changed around each lesson, so that children experience the games with different players. Children who are not placed within groups for any reason can complete individual worksheets
4. The teacher/TA should move around the class, watching each of the groups, to make sure that games and particularly the right levels of the games, are being played.
5. Clearly, the first session in a week when children are learning new games, will be more taken up with explaining. By session 2, it should be possible for children to immediately start playing the game as soon as the lesson begins.
6. At the end of the lesson, it is worth taking a moment to sort all the cards and games so that they are ready to play next time.

2. Small group games

2.1 Snakes and ladders

Material

Board
Dice
Playing pieces

Introduction

Snakes and ladders is one of the best known board games. Players travel up ladders and down snakes to help them move from 1 up to 100.

Can you land on the final square before anyone else?

Game structure

Players roll the dice to see who goes first: highest scorer starts. Play then moves to the child on their left and so on.

To take a turn, roll the dice and move your piece forward by that number of spaces on the board. If you land exactly on a square at the bottom of a ladder, you go up the ladder. If you land exactly on a square with the head of a snake, you go down the snake. If you roll a six, you get an extra turn. Move your piece forward six squares then roll again. You must land exactly on the last square to win. If you roll too many, you ‘bounce back’ off the last square and move backwards. You can only win by rolling the exact number needed to land on the last square.

Variant I

Patience is a virtue. When you get towards the end of the board, instead of ‘bouncing back’ if you don’t get the right score, you must wait until you roll exactly the right number.

Variant II

Topsy turvy world. Start at the end of the board and count backwards. Snakes are now good and ladders are bad!

Variant III

Each player rolls twice. They must use one roll to move their own piece. With the other roll they can choose whether they move their own piece or someone else’s piece.

2.2 Uno

Material

Cards numbered 1-9 in yellow, blue, red and green
Change direction cards (arrows)
Miss a turn cards (no entry sign)
Pick up +2 cards (coloured with +2 in the corner)
Pick up +4 cards (black with +4 in the corner)
Change colour cards (black with all four colours in the middle)

Introduction

A classic card game often seen played on European beaches in the summer.

Can you be the first to get rid of all your cards? And don't forget to say 'Uno'!

Game structure

Each player is dealt 7 Uno cards. The rest of the cards are put in a pile (the draw pile) except the top card which is turned face up. This second pile becomes the discard pile. The first player (the one to the left of the dealer) has to put one of their cards on the face up pile; the card must match by colour or number (or both). If they do not have a card that matches, they must pick up a card from the draw pile. Wild cards (the cards with features other than numbers) can be played at any time instead of a number card, provided they match colour. +4 cards and change colour cards do not need to match. As you approach the end of the game and you're down to one card, you must, during your go call out 'Uno' (meaning 'one'). If you fail to do this, you will receive 2 cards from the draw pile as penalty. If you manage to play your last card, you will be the winner.

Variant I

Play with only number cards, change of direction and miss a turn cards

Variant II

Add +4, +2 and change colour cards too – ie now full set of cards in play

Variant III

Scoring! Now you need to keep score. They player who goes out scores *the sum of all the cards the other players have left in their hand*. Add up all the number cards left in the hands of all your opponents and write down the total. The first to get to 100 is the overall winner.

2.3 Brainbox

Material

Set of Brainbox playing cards
Hourglass timer
Dice

Introduction

The object of the game is to carefully study a card for a fixed amount of time, then answer a question about it correctly. The question asked depends on the roll of a dice. If the question is answered correctly, the player keeps the card. The player with the most cards at the end of the game is the winner.

Can you win the most cards by being the memory champion?

Game structure

All children act as both player and questioner. Each child takes a card from the box. On a given queue (Go!) the timer is turned over and the children study their own card for the fixed length of time. (If the timer is too quick, feel free to turn it over again). When the time is up, each child passes their card to the player on their left. The first child rolls the dice and their questioner (ie the child holding their card) reads out the question matching that number. If they get it right, they keep the card and play passes to the next child. If they get it wrong, the card is returned to the back of the box of cards.

Variant I

Answer one question correctly to win the card

Variant II

Each child must answer two questions on each card correctly to win the card

Variant III

Double up. Children take *two cards at a time* to study and have to correctly answer one question from each to win the card

2.4 Scrabble

Material

Scrabble board
4 tile holders
100 letter tiles in a bag
A dictionary
Paper and pencil to keep score

Introduction

One of the classic word games, the challenge is to build up a crossword, with each player adding a single word to what has gone before. The letters a player puts down must make at least one new word and must not create any non-words. Tricky letters score higher and if you plan carefully, you can get your words down on double or triple boxes on the board to boost your score.

Can you score the most points by thinking up lots of great words?

Game rules

To see who goes first, each player takes a letter; whoever has the letter closest to A in the alphabet goes first. All players then pick out 7 letter tiles from the bag (no peeking!) and lay them out on their tile holder so that other players can't see. The player who won the draw goes first and must put down a word of at least two letters so that it crosses the star in the centre of the board. It can go horizontally or vertically but not diagonally. The star counts as a double word score so the score for that player is the sum on the letter tiles, doubled. Once the player has put a word down, their score should be written down, and then they pick up the same number of new letter tiles from the bag as letters they put down. The play then passes to the player on the left. Their word must connect with at least one letter on the word already on the board. If anyone doubts whether a word is real, check in the dictionary. If it comes to your go and you are really stuck, you can swap tiles you don't want instead of having a turn putting down a word.

Variant I

The regular game as above.

Variant II

A speed element is introduced. Each child is only given one minute for their go.

Variant III

All words must fit a given theme eg animals and plants, things in the home, history etc. The players can choose their own themes.

2.5 Rummikub

Material

Number tiles in red, orange, yellow and black and numbered 1-13
4 tile holders
2 'joker' tiles – these can act as any tile you want

Introduction

Based on the card game 'rummy', the aim is to get rid of all your tiles before the other players do. First you have to collect sets (see below) and put them out, then you have to watch the developing play to see new opportunities to put down your tiles on other players' sets.

Can you get all your number tiles out before anyone else?

Game structure

Turn the tiles so they are all face down and shuffle them around. Choose a number tile to see who will go first – highest number starts. Each player then selects 14 tiles and puts them on their tile rack so that no-one else can see. You need to find 'groups' which are collections of *at least three.* There are two types of groups: 'sets' of the same number in different colours (eg red 4, orange 4, black 4) or 'runs' which are collections of at least three consecutive numbers in the same colour (eg black 5, black 6, black 7).

When it is your turn, you can either put down tiles or if you can't put down tiles, you pick up a tile. You can either put down a set, a run, or both; once you have put down at least group, you can also add tiles to other people's sets (eg if someone has a run of black 5, 6, 7, you can add black 8 or black 4 to their run). You can also break up groups that have been put down and re-use the tiles in them, as long as you can complete your moves straight away with no tiles left over. Eg You can split a run of red 10, 11, 12, 13 to take the 10 to go with a black 10 and a blue ten you have in your hand. You can never leave or make a set with less than 3 tiles in it. A joker can act as any tile (eg if you have a blue 8 and a red 8, you could use the joker to make the third 8). When you have played your last tile, say 'Rummikub' and you have won the game.

Variant I

Play the version as above, except loosen the rules so that runs can be any colour rather than all the same colour (eg black 5, red 6, orange 7 is allowed).

Variant II

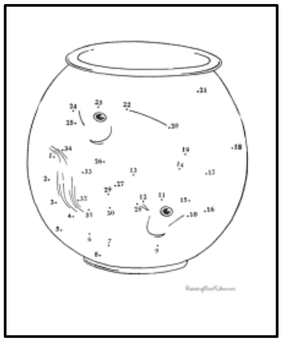
Runs must now be all the same colour.

Variant III

Introduce scoring. Once someone is out, their score is calculated by adding together the numbers on the tiles everyone else still holds in their hand. Each player must add their own and the winner must add them all together.

3. Individual games

3.1 Dot-to-dots



Material

10 x dot-to-dot puzzles
10 x solutions

Instructions

Starting with the dot numbered ‘1’, the aim is to join all the dots in the right order (1, 2, 3 etc) to form a picture.

Levels

Sheets are grouped into three different levels of difficulty:

Beginner (3 sheets)

Intermediate (4 sheets)

Advanced (3 sheets)

3.2 Wordsearches

Material

10 x wordsearch puzzles
10 x solutions

Instructions

Beneath each puzzle is a list of words to find in the grid above. The words can be in any direction, horizontal, vertical or diagonal and might go forwards or backwards. When you find a word, mark it off on the grid and tick it off on the list beneath to show you have found it.

Levels

Sheets are grouped into three different levels of difficulty:

Beginner (3 sheets)

Intermediate (4 sheets)

Advanced (3 sheets)

3.3 Crosswords

Material

10 x crossword puzzles
10 x solutions

Instructions

The rules of crosswords are very simple. Just find the answer to the word given by each numbered clue (across or down) and fill it in the grid. One blank square is for one letter. Someimtes you might be able to think of more than one answer for a clue; in that case leave it, find some other answers and come back once some of the letters are filled in. Each clue has a number in brackets after it like this (3); this tells you how many letters are in the word. Sometimes a clue has two different parts, in which case the parts will be separated by a semi colon (one of these ;). If you want to really test yourself, you can also time how long it takes you to complete a puzzle.

Levels

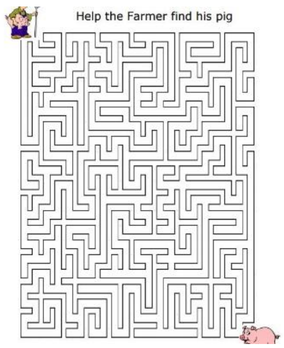
Sheets are grouped into three different levels of difficulty:

Beginner (3 sheets)

Intermediate (4 sheets)

Advanced (3 sheets)

3.4 Mazes



Materials

10 x mazes
10 x solutions

Instructions

The mazes are made up of branching passages through which you must find a route, starting at ‘In’ and ending at ‘Out’. Whatever the shape of the pathways, the walls are fixed and you cannot jump over them. If you reach a dead end, you have to either turn around and go back or return to the start and try again.

Levels

Sheets are grouped into four different levels of difficulty:

Beginner (2 sheets)

Intermediate (3 sheets)

Advanced (3 sheets)

Ace (2 sheets)

3.5 Sudoku

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Materials

10 x worksheets
10 x solutions

Instructions

All sudoku have a square grid of large squares, with smaller squares inside. The basic rule of the game is every column and row must have *all of the numbers from 1 to 9*. That means that within a row or column, a number cannot repeat. In addition, every number from 1 to 9 must also appear in each of the large squares, only once each. So, if a large square already has the number “2” in it, you know it can’t include another number “2” anywhere in the square.

All sudoku start with some numbers already filled in; the easier the puzzle, the more squares already filled in.

The aim of the game is to fill in the whole grid with the right numbers. It’s best to use a pencil so you can rub out any mistakes!

Levels

Sheets are grouped into four different levels of difficulty:

Beginner (3 sheets)

Intermediate (4 sheets)

Advanced (3 sheets)