Chapter 14: Leonardo da Vinci's apprentices or tinkering belles and boys at ludic play?

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Abstract Children are naturally curious and inquisitive about their worlds (Spektor-Levy et al., 2013) but to stimulate their curiosity and motivation to learn educators must provide potentiating environments in which they can work creatively to apply their knowledge and skills (Claxton & Carr, 2004). In this chapter the researcher outlines a teaching initiative '*da Vinci's Apprentices*', in which an educator guided apprentices through an iterative engineering design process. This initiative was developed to situate the practices of doing science and engineering across subject boundaries (Papert & Harel, 1991; Kangas, 2010). The design of *da Vinci's Apprentices* was informed by Hutt's (1981) taxonomy of play, Craft's (2002) conceptualisation of creativity as possibility-thinking, imagination and combinatorial play and, Heathcote and Bolton (1995) pedagogy of dramatic inquiry. An example of a dramatic inquiry focusing on a bridge commission is presented in this chapter to show how creative thinking was integral to children's initial ideation and in their development of engineering solutions to resolve problems.

Introduction

Leonardo da Vinci (1452 -1519) was an Italian polymath (from the Greek polymathes) who "learned much […] in different fields of study" including art, architecture, anatomy, mechanics and engineering (Kron & Krishnan, 2019, p. 403). He lived during the Renaissance, a time when art, architecture, science and engineering were closely linked, and innovation and invention flourished. The understanding he acquired in one domain he readily applied in other fields of knowledge, because he was free to think, without the imposition of artificial subject boundaries.

Endlessly curious, da Vinci investigated a range of phenomena in the world around him, using drawings, annotated diagrams and mirror-written reflections to capture his observations and his possibility thinking that would inspire future creative endeavours (West, 2017). Curiosity is recognised as an antecedent to learning (Litman, 2005). Curiosity is also a necessary pre-requisite to foster creativity including the generation of ideas (Hardy III et al., 2017), possibility thinking (Craft, 2002; Craft et al., 2005) and "imaginative activity fashioned so as to produce outcomes that are both original and of value" (National Advisory Committee on Crea-

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tive and Cultural Education, (NACCCE), 1999: 30). Like da Vinci, children are naturally curious and inquisitive about the phenomena they encounter in their worlds (Spektor-Levy et al., 2017). In England, the Office for Standards in Education (Ofsted, 2013) report '*Maintaining Curiosity'* identifies effective science teaching as that which "sets out to sustain pupils' natural curiosity" (p. 5).

Heathcote and Bolton (1995) developed the dramatic inquiry pedagogy, Mantle of the Expert (MoE), in which educators position pupils as experts within a dramatic frame. The researcher created a sequence of teaching interventions, '*da Vinci's Apprentices'* to connect children's learning experiences in science, design technology, humanities and arts within creative contexts. This approach uses the pedagogy of dramatic inquiry (Heathcote & Bolton, 1995) to situate the practices of doing science and early engineering in imaginary contexts that cross subject boundaries (Papert & Harel, 1991; Kangas, 2010).

An exploratory case-study was carried out with a class of primary pupils aged 10 to 11 years, (N=50) to examine the "particularity and complexity of a single case" (Stake, 1995, p. xi). The aim of this study was to demonstrate how the deployment of this initiative supports children's creative thinking during their initial generation of ideas (Craft, 2002, Hardy III et al., 2017) and in their resolution of problems as they apply their scientific knowledge to meet a rubric of scientific criteria.

Dramatic inquiry, framing and improvisational roles

Craft (2005, p.44) observed that "a pedagogy which fosters creativity depends on practitioners being creative to provide the ethos for enabling children's creativity". Heathcote and Bolton (1995) developed the dramatic inquiry pedagogy, *Mantle of the Expert* (MoE), in which educators position pupils as experts within a dramatic frame. Dramatic inquiry supports whole class improvisation by situating problem-based learning in fictional worlds that mirror authentic contexts (Brown, Collins & Duguid, 1989; Krajcik, & Blumenfeld, 2005). Whole class improvisation can facilitate pupils' agency and creative thinking in the context of problem-based learning (Krajcik & Blumenfeld, 2005) when the educator shifts responsibility for decision-making to pupils.

In *da Vinci's Apprentices*, the educator positions pupils as apprentices, tasked to travel back in time to complete STEAM commissions, by seeking ideas from more knowledgeable scientists. Apprentices travel by Time Machine to scientists' places of inspiration, if known, for example, their dreaming places, (Alexander Graham Bell), libraries (of Alexandria or Ephesus), laboratories, exploratoria or invention centres (Menlo Park, Thomas Edison). The educator is positioned as an intermediary who initially contextualises the improvisation, introducing the commission or request for help from a patron, then acting in-role as the scientist and acting as a co-investigator alongside children. In these multiple roles the educator guides apprentices through an iterative engineering design process (EDP) enabling them to define the problem and to imagine a range of possible ideas that may contribute towards a possible solution (Fig. 14.1):

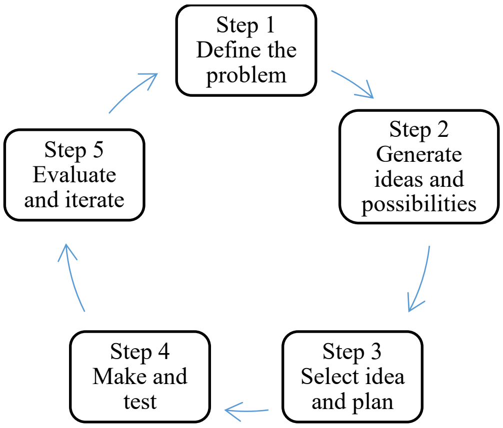


Fig. 14.1 An engineering design process followed during dramatic inquiry

Arnold and Clarke (2014, p.746) argue such pedagogical approaches facilitate the emergence of children's collective agency because "social meaning is made at the nexus of 'positions', 'storylines' and 'acts/action'." They maintain:

> in positioning theory, a storyline is discursively performed when participants accept the affordances and constraints conferred on their speech acts by the conventions of the particular storyline (p.746).

However, whole class improvisation requires learners to be simultaneously aware of two distinct worlds, the physical reality of the actual world and the fictitious, imagined world co-constructed through a process called metaxis (Boal, 1995). In drawing on the socio-cultural theory of Vygotsky (1978) Dorion; (2009) explains learners navigate these two distinct worlds concurrently by maintaining two dialogues, an internal dialogue with themselves and a shared external dialogue with their educator and fellow participants wherein:

> a semblance of truth sufficient to procure for these shadows of imagination that willing suspension of disbelief for the moment, which constitutes poetic faith (Coleridge, 1871, Chapter XIV).

Playful learning

The arrival of a commission at *da Vinci's Apprentices*' workshop provides groups of children with opportunities to define a problem, design, construct and evaluate an artefact that meets a rubric of criteria. Dewey (1916) observed when children are supported in their interactions with materials their initial explorations and interactions progress through "trial and error […] their inquiries are spontaneous and numerous, and the proposals of solution advanced, varied and ingenious" (p.183). Indeed, children's interactions with materials could provide opportunities for both goal-orientated (telic) and recreational (paratelic) play (Apter, 1991) as they bring these physical artefacts into existence. Hutt (1981) observed and classified children's everyday types of play with materials and objects and delineated three types: epistemic, ludic and game play with rules.

Hutt (1981) characterised children's epistemic play with objects and materials as that based in knowledge seeking, wherein children ask what can this object do? In contrast she classified ludic play with objects as a context in which the child asks, what can I do with this object? During both epistemic and ludic play with objects and materials it is "the threshold of desired uncertainty in the environment which leads to exploratory behaviour" (Jirout & Klahr, 2012, p. 150). Children's curiosity drives learning because the physical materials made available offer a range of affordances (Gibson, 1976), provocations, and possibilities (Craft, 2005) prompting question-posing.

From a socio-cultural perspective, the generation of questions and the construction of concepts are psychological tools of the mind that support the development, organisation and elaboration of thinking (Vygotsky, 1978). Edwards and Mercer (1987, p. 20) maintain "talk is one of the materials from which a child constructs meaning", however, Lave (1988) and Hutchins (2000) extends this notion to embrace gestures, actions and interactions between individuals and individuals and objects or materials. Within their groups, the development of a shared understanding between apprentices is dependent upon the social distribution of cognition across individual apprentices' minds, bodies, objects and materials (Hutchins, 2000).

In contrast, ludic play encompasses socio-dramatic play that supports language development and imaginative ideas wherein children create fictional worlds, taking on roles and solving problems as a character within these worlds through improvisation. Vygotsky (1978) believed the development of cognitive processes including imaginative thought and understanding is founded in social interactions and mediated by cultural signs. Smith (1982), cited in Smith, 2016, p. 247 suggests the elaboration of both exploratory and social play into fantasy or symbolic play may have provided humans with the evolutionary advantage of inventiveness. The workshop in which these initiates are apprenticed is framed as a polymathist centre of learning. The procurement and creation of semiotic resources including artefacts, symbols and signs associated with scientists, science and technology enables educators and pupils to bring to life the dramatic frame through a process of transmediation (Kress & van Leeuwen, 2001).

Murcia et al (2020) developed a framework identifying criteria that characterise children's creativity focusing on four components: product, person, place and process (Table 14.1).

Table 14.1 The 'A' to 'E' of creativity: A framework for young children's creativity (Murcia, et al., 2020.)

PRODUCT: Criteria for creative outcomes	
ORIGINAL	FIT-FOR-PURPOSE
PERSON: Perspectives on who does the original thinking	

CHILD ENGAGED BY EDUCATOR'S CREATIVITY	CHILD'S CREATIVE DOING	CHILD'S CREATIVE THINKING
PLACE: Elements of an enabling environment		
RESOURCES	COMMUNICATION	SOCIO-EMOTIONAL CLIMATE
Intentional provocations	Intentional learning conversations	Stress and pressure free environment
Stimulating materials	Hearing and valuing children's ideas	Non-prescriptive
Adequate materials for everyone	Open inquiry questioning	Non-judgemental
Time for creative exploration	Facilitating dialogic conversations	Allowed to make mistakes

PROCESS: Characteristics of children's creative thinking				
AGENCY	**B**EING CURIOUS	**C**ONNECTING	**D**ARING	**E**XPERIMENTING
Displaying self-determination	Questioning	Making connections	Willing to be different	Trying out new ideas
Finding relevance and personal meaning	Wondering	Seeing patterns in ideas	Persisting when things get difficult	Playing with possibilities
Having a purpose	Imagining	Reflecting on what is and what could be	Learning from failure (resilience)	Investigating
Acting with autonomy	Exploring	Sharing with others	Tolerating uncertainty	Tinkering and adapting ideas
Demonstrating personal choice and freedom	Discovering	Combining ideas to form something new	Challenging assumptions	Using materials differently
Choosing to adjust and be agile	Engaging in "what if" thinking	Seeing different points of view	Putting ideas into action	Solving problems

This framework enables an educator to deconstruct and critically evaluate the characteristics of children's creative thinking in each step of the EDP during a dramatic inquiry.

Research design

A small-scale, exploratory case-study is presented in this chapter. The study focused on a workshop that took place over two days during National Science Week, in the North of England. Two groups of pupils aged 10 to 11 years, participated (N = 50). The aim of this study was to demonstrate how *da Vinci's Apprentices* supports children's creative thinking during their initial generation of idea (Craft, 2002, Hardy III et al., 2017) and in their resolution of problems as they applied their scientific knowledge to meet a rubric of scientific criteria.

A case-study approach was taken as it is an empirical inquiry in which the 'boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used' (Yin, 1984, p.23). This approach enabled the researcher to examine in depth the 'particularity and complexity of a single case' (Stake, 1995, p. xi) and to understand the value to pupils in using this pedagogical approach.

Ethical considerations

Ethical approval to undertake research was obtained from the researcher's employing university and permission to participate in the study was granted by the Headteacher on behalf of parents and children in accordance with the school's policy guidelines.

Data collection

Data was collected using participant observations supported by field-notes, video-recordings and examination of children's models and drawings. Throughout the workshops the researcher was positioned as a participant observer, taking part of the events being studied, in order to identify the inter-play of variables that support the emergence of children's creativity (Denscombe, 2010). As a participant observer the researcher could also lead the teaching initiative, becoming immersed in the social worlds of two classes in order to experience and to "reflect the detail, the subtleties, the complexity and interconnectedness' of these social worlds" (Denscombe, 2010, p. 206). O'Leary (2004) also asserted that it is impossible for a researcher in this dual role to be objective because their observations must be subject to fluctuations in attention and biased in the selection of observational foci and the reactivity of pupils. To counteract subjectivities, video-recordings were made of the workshop and these were transcribed immediately afterwards, to ensure accuracy of verbal exchanges. The use of video technology to record observational data provides a detailed and accurate record of what is taking place in the field.

An illustrative example: The Bridge Commission

The Bridge Commission example was chosen because it is representative of the dramatic inquiry approach and enabled the researcher to evaluate to what extent children were supported to be creative at each step of the Engineering Design Process. It also illustrates the model and provides teaching strategies that could be adapted for delivery in a primary school setting.

Step 1 Define the problem

The story *Iggy Peck, Architect* (Beatty, 2007) is shared with children to introduce images of bridges and essential vocabulary including the terms: beam, arch, cantilever, suspension, deck, abutments, keystone, and span. Further discussion of the story is interrupted by the arrival of a special commission from a client, *Future Worlds.*

Problem: An old bridge has collapsed, trapping the residents of an island who are threatened by rising tides and further flooding. Children must travel to seek ideas for bridge designs from Leonardo da Vinci and use these to inform their own designs. Each bridge must meet a rubric of scientific criteria (Table 14.2).

Table 14.2 A rubric of scientific criteria used to evaluate each bridge design

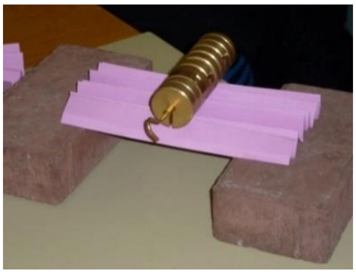
TEST	Performance	Test Criteria	Equipment	PASS	FAIL
Dimensions	The bridge enables 'passengers' to cross a gap of 50 cms (minimum).	The bridge has a span of 50 cms. A wind-up toy and marble can travel across the bridge.	1 metre ruler		
Stability on land	The bridge is stable on the surface of a table.	The bridge stands securely on a display table.	Display table, timer.		
Stability in water	The bridge supports remain stable in water. The bridge supports remain intact in water.	The bridge stands for 10 mins in a water tray.	Water tray and timer.		

Strength	The bridge withstands the weight of falling objects during storms.	The bridge can support an increasing load minimum 2 kg.	kg and 600g masses		
Wind resistant	The bridge remains intact during severe winds.	The bridge stays intact when blasted with a hair-drier for 5 minutes.	Hair drier		
Visual Appearance	The bridge contains recognisable shapes and symmetry.		Aesthetic appeal to individual.		
Additional tests required by apprentices (for innovations)					

Apprentices travel to da Vinci's workshop, in 1502, with copies of the commission and the rubric. Leonardo (educator-in-role) is present in the workshop surrounded by sketches of beam bridges, arched bridges, bridges with gate towers and drawbridges. He explains Sultan Bayezid II, leader of the Ottoman Empire has issued a commission inviting artists, architects and engineers to create designs for a new bridge to span the Golden Horn River. The bridge will link the cities of Constantinople (Istanbul) and Galata. He has submitted a design for an arched bridge and is waiting to hear if his design been successful. Leonardo shares his design for the bridge with the apprentices explaining its features and answering children's questions. Apprentices share news of their commission and rubric of scientific criteria. Leonardo expresses delight at the task and invites children to take part in some practical inquiries to examine key concepts related to bridge design eg stability and strength. In his workshop apprentices investigate the strength of materials by testing and comparing the different loads that can be supported by one sheet of paper, when folded in different ways, e.g. flat, arched (Fig. 14.2), folded into a cylinder or concertina (Fig. 14.3).

In this arched arrangement a single piece of paper supports a greater weight because the force exerted by the massses (load) is distributed across the curve of the paper bridge.

Fig. 14.2 Testing an arched structure



When folded in a concertina this single page paper bridge can support a greater weight because the load is distributed across the triangular structures.

Fig. 14.3 Testing the strength of a concertina structure

Guided by da Vinci, children's prior learning is operationalised, extended and made readily available for application in the context of their real-world problem. Da Vinci demonstrates how the blocks from which an arched bridge is constructed are held in place by the force of compression. This force pushes outwards in both directions from a centrally positioned key stone (the keystone) and is distributed along the curve into the abutments.

Step 2 Generate ideas and possibilities

Apprentices return to the present time and examine photographs of a range of bridges. The educator introduces the process of morphological analysis (Zwicky, 1969) in which apprentices write down key words, on a drawing board (consensus placemat) (Kagan, 1994) using ideas from all of the sources examined. This exercise allows children to engage in possibility thinking through word associations (Craft, 2002). Pedersen and Burton (2009, p.29 cited in Newton & Newton, 2014, p. 583) observe these preparatory inquiries function as antecedents of creativity in real word design, arguing that supporting learners "to generate ideas is important, but equally important is preparing them to recognise ideas and use ideas from a variety of sources".

Step 3 Select ideas and plan

During the planning phase all responsibility for decision-making is shifted to children and no directions or instruction sheets are provided. The rubric of scientific criteria provided guidance to children on the kinds of tests their completed bridge would have to pass to be successful. Apprentices are invited to summarise the features they would like to include in a bridge design, justifying decisions and anticipating problems. They then create individual annotated drawings of a bridge, containing these key features. These drawings are pinned onto a display board and using post-it-notes, apprentices vote for one design they would like to make and test. Collectively apprentices plan how they will proceed. This process allows all children to express and make visible their ideas.

Step 4 Make and test

Apprentices deconstruct, combine and recombine materials while interacting with one another using talk and gestures, until they bring into existence a physical artefact that meets a rubric of scientific criteria (Lave, 1988; Hutchins, 2000. The educator supports children by acting as a curious and naïve fellow investigator as they pursue diverging lines of enquiry by testing out their ideas first-hand—or through secondary research. When the bridge is completed, groups test the performance of their models using the rubric of scientific criteria to evaluate its performance.

Step 5 Evaluate and iterate

Following the testing phase children engage in peer review and reflection to discuss the performance their bridges and to receive critique using a group-to-class feedback forum. Groups of apprentices identify possible ways to enchance the performance of their bridges and request further advice for improvement from other groups. The educator explains if a design is unsuccessful during the testing phase, following reflection and peer review the designers must ‘go back to the drawing board’ and modify their bridge design. Finally working in pairs as plenary pals, children are encouraged to summarise their experiences of working through an EDP. This process enables the educator to activate pupils as learning resources for one another (Wiliam & Thompson, 2007) and supports the development of children’s metacognition.

Findings

During the workshop, in response to the commission, each team of apprentices produced plans, drawings and an artefact that could be tested using the rubric of scientific criteria. Artefacts were brought into existence as a result of children’s talk, gestures, physical interactions and combinatorial play with materials, and with one another. A video-recording of the workshop was made and transcribed, supported by the researcher’s fieldnotes. Episodes of creativity demonstrated by Group A, at each step of the EDP, are deconstructed and analysed below using Murcia et al's, (2020) framework (Table14.3):

Table 14.3 Deconstructing children's creativity at each step of the EDP

Step in the EDP	Characteristics of children's creativity demonstrated during the dramatic inquiry
Step 1 Define the problem	**Place:** Children demonstrated curiosity, an antecedent of creativity during the story-telling session and at the arrival of the commission prompting question-posing. Da Vinci's workshop provided a range of materials and objects that offer affordances to children encouraging combinatorial play and experimentation (Craft, 2002) e.g. they began discussing which objects and materials floats/sinks; waterproof/not waterproof; they realized they could test, combining or fold materials.
Step 2 Generate ideas and possibilities	**Person**: Initially apprentices were guided through the process of morphogenesis to facilitate ideation drawing on sources including their prior learning, the storybook, the commission, the rubric, da Vinci's bridge design and their reflections on the learning acquired in the practical investigations and images of different bridges. They deconstructed the wording of the commission and the rubric of scientific criteria. They wrote down key words and generated all possible word associations, links and ideas in response to the key terms e.g., strength. Each apprentice mapped their ideas onto a collaborative 'drawing board'. Child A drew on previous knowledge from swimming lessons concerning the function and use of floats and attempted to persuade others to apply this knowledge in their design. The educator was sufficiently curious about children's ideas and flexible in encouraging children to research such possibilities. The educator asked this group to add the criteria 'floats for ten minutes' to their rubric, in the additional criteria column, because this was an agreed and an intentional design feature. **Process:** Using the iPad children searched for floating bridge and discover such bridges exist—built on pontoons. A further search of the term 'pontoon' yielded the explanation 'a watertight float or vessel used where buoyancy is required in water as in supporting a bridge…' (Collins on-line English dictionary) further supporting possibility thinking along this line of enquiry (Craft, 2002). When all of the children realised such bridges existed their design became a real possibility and agreed to construct and test it.

Step 3 Select idea and plan	**Process:** This rubric together with the materials available offered affordances and constraints to children allowing them to be imaginative in their planning ideas. Children used talk, gestures and physical interactions when explaining their ideas to one another and when combining and considering which materials to select. **Person:** Children demonstrated agency in their decision-making and choice of materials throughout the planning phase. This included examining the affordances offered by the materials by asking 'What does this object do?' and 'What can I do with this object?' leading to experimentation.
Step 4 Make and test	**Person**: Using the rubric of scientific criteria as a source of reference groups select materials to use, or to test prior to use, to bring their design into existence. Children's interactions progressed through trial and error. Again, the educator acted as a fellow investigator—encouraging but not directing. **Process:** Children pursued lines of enquiry by testing out their ideas—to see if their possibility thinking resulted in a resolution—or through secondary research. Groups test the performance of their models using the rubric of scientific criteria to support their judgements. **Product**: Children began combining and recombining materials and interacting with one another using talk and gestures, until they brought into existence a physical artefact—Floating Bridge—to meet a rubric of scientific criteria.
Step 5 Evaluate and iterate	**Product**: A physical artefact 'Floating Bridge' was produced. This bridge was declared fit for purpose passing all tests outlined on the rubric of scientific criteria and was original to the group. Group A worked collaboratively to create a pontoon bridge with a floating platform composed of small rafts each made from lollisticks and corks, with an upper deck for foot passengers. Following the testing phase children discussed the performance their bridges using a group-to-class feedback forum. Groups identified possible ways to enhance the performance of their bridges requesting further advice for improvement from other groups. The educator shared news that da Vinci's design was rejected by Sultan Bayezid II because it looked unexciting. This aspect of the teaching initiative modelled to children that great scientists experienced rejection and failure, but cope by adopting a resilient, determined frame of mind. Apprentices learned that in recent years a team of architects and engineers from the Massachusetts Institute of Technology successfully built a prototype of da Vinci's bridge

	design using his drawing. This bridge design would have also survived earthquake shockwaves, saving lives in an earthquake prone area (Chandler, 2019).

Within dramatic inquiry, talk supported the process of knowledge elaboration. An extract of dialogue reveals how children in Group A used talk to generate and explore ideas and to evaluate the feasibility of making a bridge that could float:

Educator	Oh, that looks interesting, can you explain what you're thinking about here (points to the sketch).
Child A	It's a float for when it rains…
Child B	(Interrupting) …and if it floods, not just rains.
Child A	(Gesturing) Yes, well if it floods the bridge will float on its floats. It floats anyway. It will be a floating bridge.
Child C	(Shakes head in doubt) No, it won't, it will get washed away. It will smash. The other bridge fell down in the rain, this one will fall down.
Child A	No (shaking head and holding hands up in a cup shape) it fell down because it didn't float, if it could've floated it would've floated, I mean it wouldn't have fallen down.
Educator	What are these? (Points to 4 square grids below the deck of Child A's bridge design).
Child D	Floats They are all float-rafts. That's a raft (pointing to 4 flotation structures). That's a raft.
Educator	Where did you get that amazing ideas from? Have you ever seen or been on a floating bridge?
Child C	(Looking surprised) Do they have them? Are they real?
Child A	We've been using floats in swimming to strengthen our legs. So, I thought we could use floats under the bridge.
Educator	Well, you could use an iPad to find out and then you can decide if you could all make it work. If you can imagine it—you can make it happen.

Discussion and implications for classroom practice

Throughout the implementation of this adaptation of dramatic inquiry, improvisation supported pupils' agency and creative thinking in the context of a STEM challenge.

The provision of a rubric of scientific criteria supported children's creative thinking by placing demands upon them that influenced their collective decision-making. For example, the final artefact produced was required to fulfil specific criteria, these requirements provided both constraints and affordances; relating to the resources made available provoking possibility thinking, experimentation and combinatorial play. This resulted in episodes in which children alternated between epistemic and ludic play, asking themselves what does this object do and what can I/we do with this object? The rubric thus grants groups of children sufficient agency and autonomy to make decisions with reference to peers, rather than to their educator.

Within this improvisation talk was key to the generation and development of children's ideas and the inter-connection of these ideas enabling the elaboration of creative thinking and facilitating decision-making. Talk enabled children to engage in the process of morphogenesis, ideas generation, through the use of word associations and annotated drawings. Use of a consensus placemat style 'drawing board' (Kagan, 1994) encouraged idea generation, allowing all children to contribute a diverse range of ideas and to make all children's thinking visible to the group; encourages tangential and divergent thinking. Providing these opportunities to allow children to map all possible ideas stimulates possibility thinking that constitutes creative thinking, as they formulate ideas, experiment with ideas, share, explore and refine ideas with others (Craft, 2002).

Talk also facilitated effective reflection and peer reviewing processes. Opportunities for peer review both prior to and after testing were very important to emphasise to children the primacy of evidence and testing as a basis for decision-making, generating explanations and understanding, correcting misconceptions and activating learners as resources for one another.

The availability of technology, while pursuing a line of enquiry, facilitated children's autonomous, in-the-moment research, for example, during their search for 'floating bridge', while the discovery of 'pontoon' generated such excitement at the realisation their possibility thinking was physically feasible.

Limitations of the study

Given the unique nature and particularity of the teaching initiative, *da Vinci's Apprentices*, the transferability of the study's findings to other teaching initiatives are limited because they cannot easily be generalised to the wider population, however Opie (2004) argues:

> The merit of any piece of educational research is the extent to which the details are sufficient and appropriate for an educator working in a similar situation to relate his/her decision making to that described. In short, the reliability of the work is more important than its generalisability. (p. 5)

The use of video-recorded data confirmed the initiative provides a medium in which language, gestures and the manipulation of materials facilitate the creation and construction of new physical artefacts. A further line of enquiry will be to consider how the characteristics of creativity are developed through the social distribution of cognition during a STEAM Challenge. This will require observational data to examine the interactions of children with each other, through the use of language, gestures and collective reasoning with materials.

Conclusion

The deployment of an Engineering Design Process, integrated within dramatic inquiry, allows an educator to use creative, playful learning approaches, to support children's reasoning with materials, during a problem-based STEAM Challenge. By following da Vinci's polymathist approach to inquiry, children have an opportunity to connect their learning across many disciplines and to synthesise creative and innovative solutions to problems. *Da Vinci's Apprentices* is a teaching initiative that recognises the importance of operationalising children's curiosity as a necessary pre-requisite to facilitate their creativity and engagement in learning. Improvisation and the provision of a rubric of criteria support children's agency, autonomy and creativity. This adaptation of dramatic inquiry models to children that it is important to draw upon sources of ideas from more knowledgeable others and to deconstruct, play with and recombine these ideas to synthesise new and novel possibilities (Craft, 2002).

Da Vinci's Apprentices can provide educators with a means through which to design bespoke curricular projects that align with a school's long-term curricular plan. Within this initiative, children can be supported to work on specific projects from different periods of history with the assistance of a relevant key scientist/inventor using creative contexts in which to integrate science, arts and humanities**.** During the planning phase, the educator is required to undertake research about the work of the scientists, engineers and inventors who have actively contributed ideas appropriate to a topic focus. This provides educators with an opportunity to make links to contemporary problems and to make the curriculum relevant to their national, regional and local cultural circumstances, interests and concerns.

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