Chapter 4: Innovation and creativity

> “Electricity is not only present in a magnificent thunderstorm and dazzling lightning, but also in a lamp; so also, creativity exists not only where it creates great historical works, but also everywhere human imagination combines, changes, and creates anything new.”

Lev Vygotsky, 1930/1967, cited in Smolucha, 1992, p. 54

Overview

Innovation and creativity are fundamental to all academic disciplines and educational activities, not just the arts. The creative process, as with reflection considered in the previous chapter, is a critical component of making sense of learning experiences. A number of approaches to teaching and learning are considered in this chapter that help to nurture creativity and innovation. See Figure 6 for a visual overview (page 58).

What are innovation and creativity?

Innovation can be broadly thought of as new ideas, new ways of looking at things, new methods or products that have value. Innovation contains the idea of output, of actually producing or doing something differently, making something happen or implementing something new. Innovation almost always involves hard work; persistence and perseverance are necessary as many good ideas never get followed through and developed.

Creativity is an active process necessarily involved in innovation. It is a learning habit that requires skill as well as specific understanding of the contexts in which creativity is being applied. The creative process is at the heart of innovation and often the words are used interchangeably.

According to Kampylis and Berki (2014, p. 6):

‘Creative thinking is defined as the thinking that enables students to apply their imagination to generating ideas, questions and hypotheses, experimenting with alternatives and to evaluating their own and their peers’ ideas, final products and processes.’

Kaufman and Beghetto (2009, p. 6) developed four categories of creativity which help to reveal the nuances between different levels and types of creativity. See Table 11 (page 54).

Table 11: Four categories of creativity

Big-C creativity (sometimes called 'high' creativity)	Big-C creativity is reserved to describe the work of an elite few who have transformed their discipline with their inventions. Their work has been generally accepted as being innovative and ground-breaking, even if it was considered controversial when it was first created. Some examples are scientific works such as Einstein's theory of relativity and Darwin's theory of evolution, and works of art such as Picasso's Guernica, Jane Austen's novel Emma or Ludwig van Beethoven's Symphony No. 9 in D Minor. Big-C creativity is out of reach of most of us, and big-C creators themselves are often as extraordinary as their creations.
Pro-c creativity	This type of creativity has involved time (usually at least 10 years) and effort to develop. A musician who showed promise as a child, has trained to degree level and now makes a living teaching and playing classical music could be classified as pro-c. A physicist working at a university who teaches and undertakes academic research could also be classified as pro-c.
Little-c creativity	Little-c creativity is about 'acting with flexibility, intelligence and novelty in the everyday' (Craft, 2005, p. 43). This results in creating something new that has 'originality and meaningfulness' (Richards, 2007, p. 5). This everyday kind of creativity can be found in the kind of person who can resolve a complex problem at work, is a keen gardener with an eye for design, or takes creative photographs and exhibits them on a photo-sharing website. School-age learners may work at little-c level if they engage in purposeful practice in their discipline. Little-c creativity involves practice and may be developed over a long period of time. The internet has provided the infrastructure for little-c creativity to thrive. Websites such as YouTube, Instagram and Etsy enable creative people to share their expertise and work.
Mini-c creativity	Mini-c is defined as the 'novel and personally meaningful interpretation of experiences, actions, and events' (Beghetto & Kaufman, 2007, p. 73). This is the kind of creativity that can be nurtured by teachers and parents. 'Mini-c happens when a person demonstrates "flexibility, intelligence and novelty" in their thinking' (Craft, 2005, p. 19). It is usually applied, but not necessarily limited, to children's creativity. Mini-c creativity may not be visible to outsiders and may consist purely of ideas and connections that the learner creates. As Vygotsky (1967, p. 7) explains: 'Any human act that gives rise to something new is referred to as a creative act, regardless of whether what is constructed is a physical object or some mental or emotional construct that lives within the person who created it and is known only to him.' Piaget suggested that 'to understand is to invent' (1976, cited by Richards, 2007, p. 95) meaning that a learner 'invents' an understanding of new material for themselves. Mini-c creativity could describe a learner's achievement in finding several different ways of approaching a maths problem. It could also involve making a new connection between their existing knowledge and a new piece of information which helps them to understand the subject more fully.

The boundaries between these categories can be blurred and they are not age specific. A person could fit into multiple categories in different areas of their life. For example, a chef who could produce dishes at a pro-C level while at work might work at a little-c level when attending a watercolour painting class.

The two categories most relevant to schools are little-c and mini-c creativity. They highlight the fact that being creative and innovative is not so much about revolutionary ideas or new inventions that change the world. It is about individual growth achieved through small insights. Creativity and innovation are fundamental to all disciplines and an essential part of the learning process, forming an important dimension of learning how to learn, which we considered in Chapter 3. They are also fundamental to teachers improving their professional practice and to school development.

Being innovative and creative is dependent on the other attributes. Being creative requires reflection, encourages engagement and develops confidence and responsibility. The ability and inclination to be creative is essential to living a fulfilled and successful life, and it is valued in higher education and the workplace. There are many other benefits of maximising one's own creative potential such as physical and psychological health improvements, improved resilience in the face of difficulties and even lower levels of aggression (Richards, 2007, p.9).

Craft (2005, p.15) points out that our understanding of innovation and creativity have progressed and broadened over time. In the early 20th century creativity was considered to be an innate, elusive quality that individuals were born with. Initially creativity was most closely associated with the arts but grew to include science, technology and other disciplines. In the 21st century creativity is increasingly viewed as a distributed and collaborative process of communal sense making and problem solving.

As with all the learner attributes, cultural perspectives are also very important when considering creativity. Confucian heritage cultures, for example, tend to see creativity more as a collective exercise. They place responsibility for creativity on the social group rather than the individual. Individuals, therefore, are not encouraged to stand out from the class in the same way or to the same extent as in Western cultures. This does not mean that creativity is in any way less valued. As with all the learner attributes, ideas presented in this chapter need to be interpreted and implemented in a culturally sensitive way.

Creativity, innovation and learning

As discussed in Chapter 1, learning involves challenging, refining and improving understanding by being made to think hard. Sometimes, to understand new concepts and broaden perspectives, our approaches to thinking need to be creative, imaginative and lateral (incorporating new ways of looking at things), as well as linear (using existing patterns of thought).

One characteristic of the creative process that makes it particularly powerful is that it requires not only knowledge and understanding of the domain being investigated, but also a willingness to question and not be constrained by existing knowledge. Learners should understand how they can question or challenge established knowledge to help them to formulate their own understanding, and imagination can play an important role:

'One cannot think creatively unless one has the knowledge with which to think creatively. Creativity represents a balance between knowledge and freeing oneself of that knowledge' (Johnson-Laird, 1988, p.207, cited by Sternberg, 2012, p.4).

For creative thinking to deepen and extend learning, rather than be an enjoyable but superficial activity, it must be grounded in understanding of the content being investigated. It is vital that learners have sufficient understanding of the material with which they are being asked to be creative. Creative practice needs to complement diligent and deliberate practice that develops foundational skills – not be a substitute for it.

A revised version of Bloom's original 1956 taxonomy by Krathwohl (2002, p.212–218; see Figure 4) includes creativity in the taxonomy and places creativity above evaluation as a higher order thinking skill. An alternative, and probably more accurate, representation would be to include creativity as a process involved in skills at all levels represented in the taxonomy, and increasingly so with higher order skills. It might be thought that remembering factual information does not involve creative processes. In fact, as the section later in this chapter on mind maps reveals, creative approaches can be very helpful in remembering information. The processes used by champions at the World Memory Championships are highly creative as they use the mind's capacity to recognise and remember chunks or patterns that have meaning to the individual much more effectively than isolated facts.

Creative learning activities, like any other, need to respect Vygotsky's zone of proximal development with appropriate scaffolding provided by the teacher.

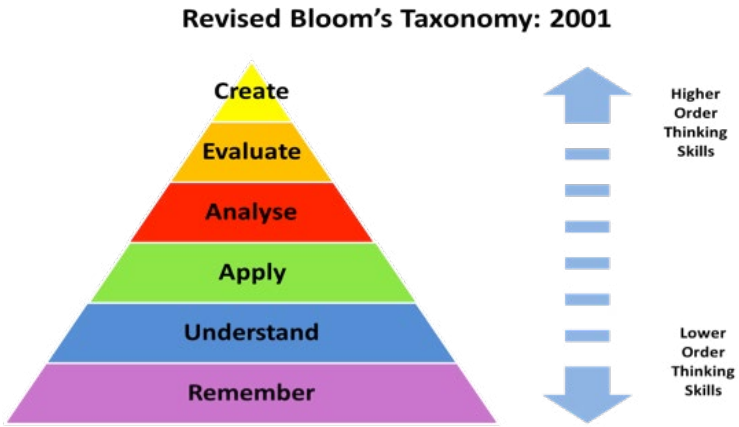


Figure 4: A revised version of Bloom's taxonomy

This is an area in which cultural sensitivity may be particularly important. If students are not used to being asked to demonstrate creative habits and skills they need to be guided. How the creative activity links to broader learning objectives needs to be clearly understood by teachers and students.

Having a creative habit, the disposition to behave creatively is critical. Csikszentmihalyi (2002, p.99) emphasises the importance of having a playful attitude while remaining disciplined. Whenever possible, play should be used to extend the range of opportunities to think. There are several character traits and learning habits that affect a learner's personal disposition, motivation and confidence to be creative. For example:

- resilience: an ability to tolerate uncertainty and persevere at a task to overcome obstacles
- not being afraid to make and learn from mistakes
- an ability to suspend judgement while generating ideas
- willingness to take sensible risks or go out of their comfort zone in their work.

A creative learner needs to be able to develop and apply a set of skills that they can use in the creative process. These include being able to:

- clarify, analyse and re-define the problem or question to uncover new ways of looking at it
- ask thoughtful questions
- notice connections between seemingly unrelated subject matter
- challenge established wisdom by asking: how would I improve this?
- recognise alternative possibilities
- look at things from different perspectives.

Creative processes usually require self-regulation, and the ideas relating to reflection and metacognition considered in Chapter 3 apply. These include learners:

- being aware of their own skills, both strengths and limitations
- thinking of a range of different strategies or approaches to use in response to a problem or question
- planning which approach to use
- monitoring their work, and being flexible enough to change to a different approach if necessary
- critically evaluating their work at appropriate points

Creating a culture of creativity in schools and classrooms

We are all born with a creative instinct and all people have creative potential. Young children naturally engage in play – a state when the imagination is used to 'try out' situations and possibilities. A cardboard box becomes a car, grass becomes food, a toy comes alive. As children mature and move through their school career, creativity can be stifled as an unintended consequence of other pressures. Students can become fearful of making mistakes if they only receive recognition for giving an answer

the teacher is looking for rather than valid original thinking and ideas. A study on creativity and innovation in education in European member states (Craft, 2005, p.21) found that teachers preferred their learners to be 'conforming' or 'considerate' to 'risk taking' and 'playful' (Ferrari, Cachia & Punie, 2009, p.21). A culture of 'one right answer' stops learners from being willing to make mistakes. They quickly learn to guess what answer the teacher has in their heads. As von Oech (1998, p.14) points out, 'many of us have been taught that the best ideas are in someone else's head'.

Like any habit, creativity can be encouraged or discouraged. Having a learning rather than a performance orientation, considered in Chapter 3, helps to create an environment where creativity is encouraged. Schools that are successful at stimulating creative learning:

- value and celebrate learners' creative and innovative contributions
- do not overcrowd the curriculum. They focus on depth as well as breadth. They manage time effectively, providing opportunities for pupils to explore, concentrate for extended periods of time, reflect, discuss and review. Students are expected to reflect deeply on the material that they are learning and to make connections between subjects and topics
- encourage a broad and balanced curriculum so that students experience a range of subjects and activities, including the arts
- encourage students not studying the arts as qualifications to pursue creative activities in the co-curricular programme
- develop codes of behaviour and classroom procedures that value and promote creativity
- encourage sensible risk taking, for example, teachers trying something new in their lessons.

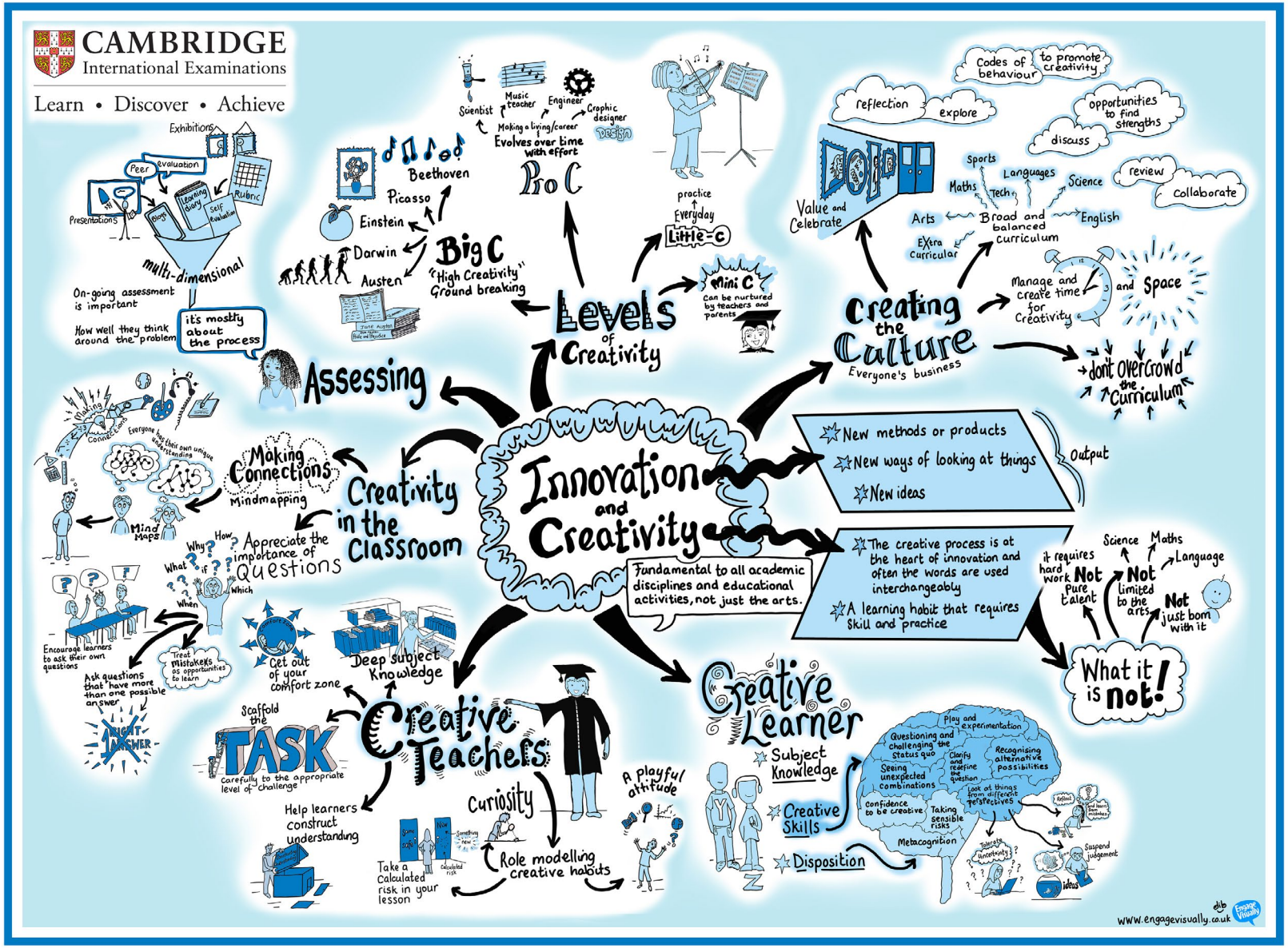
The creative process requires time and collaboration, so creating time for creative thinking activities is important. Using a flipped classroom approach for example, where learners prepare content and do written exercises preparing for lessons in advance at home, allows teachers to plan for higher-level creative thinking activities during class time. Another approach that helps students to make connections across topic areas and

Figure 5: A creativity orientation

understand the discipline as a whole is spaced delivery of content in lessons. This involves teachers revisiting related subject matter over a long time rather than just teaching each topic as a separate entity.

Creating a climate in the school by providing an environment that supports innovation can be very powerful, as Case study 10 shows:

Figure 6: Visual overview of innovation and creativity (Hover your mouse over the image to enlarge)



Case study 10:

St. Andrew's Scots School, Buenos Aires, Argentina – The Learnerspace: a new pedagogy by design

Watch the video at
https://vimeo.com/228213052

Makerspaces have become ubiquitous in schools all over the world to encourage students to apply creativity and critical thinking through design. A similar approach to learning, transforming a traditional environment into a Learnerspace can also be a great catalyst for moving pedagogy towards a learner-centred model.

Of all the many spaces in school, the school library lends itself to becoming an emblem for a new learning paradigm. In that context, we set out to embody the principles of 21st century learning through a transformation that was as profound as it was bold, and that went far beyond architectural modifications.

The first dimension of change entailed making true on the principle that learning is continuous, and transcends the physical and chronological boundaries of the classroom. By de-centralising books from the library and sending them out to school corridors and departments, we sent out the message that learning is not restricted in space and time. By allowing students to freely check out books without restrictions or controls, throughout the school, we explicitly stated that learning is a transcendent value that knows no limits or constraints.

In moving from a library to Learnerspace, the most important element of change was making sure that the redesign of the space was conducive to joyful learning. Three distinct spaces were created: a large, flexible workspace with furniture that could be rearranged freely to suit multiple configurations; a cave-like, forest-themed silent room; and a collaborative room with two projectors and floor-to-ceiling walls that students can write on. All throughout the Learnerspace, blackened walls invited students to express themselves using chalk.

Student reactions surpassed our best expectations. From being a space that students mostly used to seek refuge from cold weather, the library almost immediately became the centre of gravity of the school. Students naturally tended to occupy and make spaces come alive in ways that were hitherto unforeseen. Teachers started delivering their lessons at the Learnerspace, often sharing space with colleagues, and increasingly applying differentiation of teaching to the needs of individual learners.

And then the true joy of the learning process gradually emerged. Midday philosophy talks, quiz show-type contests, educational board games, and even a chessboard with a clock for blitz games also became manifestations that learning could be an enjoyable process.

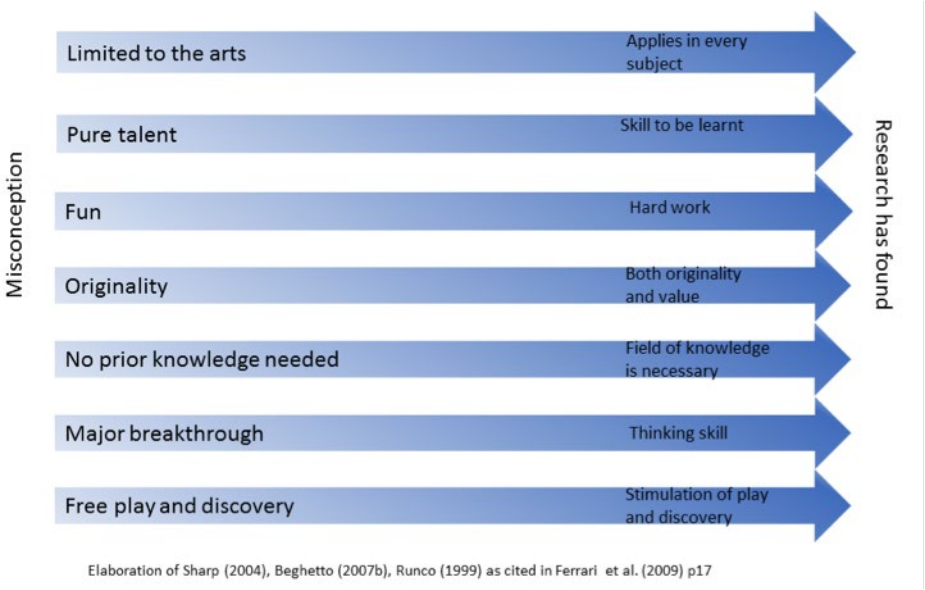
The Learnerspace embodies most of the desired learner attributes: students discuss their learning and naturally engage in metacognitive reflections, propitiated by the collaborative environment and the literal writing on the walls; they become less teacher dependent; exercise their creativity by expressing themselves actively within the space; work on the development of creative projects; take possession of the space in meetings related to their leadership roles; and create new extracurricular projects.

Many of the community forums and discussions also take place in the agora-like open space, with an openness that inspires the discussions and projects that emerge from such gatherings. The importance of the physical learning environment is often underestimated in how it can truly foster a new learning modality consistent with the modern information-rich world. Sometimes schools are daunted by the magnitude of the change required, but our Learnerspace has joyfully demonstrated that a few changes in the layout can have a substantial and inspiring effect.

Common misconceptions about creativity

Runco (1999, cited in Ferrari, Cachia & Punie, 2009, p.16) explains that people sometimes hold tacit beliefs or theories about the nature of creativity which can have detrimental effects on attempts to nurture creativity in an educational context. These theories are different from what research suggests is in fact the case. For example, many people believe that creativity is a natural talent which cannot be taught, whereas studies have shown that learners can improve their creative thinking skills with the right type of input.

Figure 7: Common misconceptions about creativity



Elaboration of Sharp (2004), Beghetto (2007b), Runco (1999) as cited in Ferrari et al. (2009) p17

Creative teachers: How can teachers help learners to develop their creative habits and skills?

'Cambridge teachers are creative, experimenting with new ideas and pursuing an enquiring approach in their teaching. They are open to new challenges, being resourceful, imaginative, and flexible. They are always ready to learn and apply new skills and techniques.'

Chapter 4 of the *Developing your School with Cambridge guide* considers the attributes of effective teachers (available at **www.cambridgeinternational.org/teaching-and-learning/**). It highlights that effective teachers have a deep knowledge of their subject as well as an understanding of how students think about subject content at different developmental stages (pedagogical knowledge). They are able to make thinking visible, helping learners to recognise misconceptions and manage their own learning. Because the creative process is fundamental to student learning, nurturing creativity is also an aspect of good teaching in all subjects.

Fostering a creative climate in the school, supportive of creative teacher professionalism, is another theme considered in the Developing your School with Cambridge guide. It is very hard for a teacher to be creative if they are following a prescribed curriculum and given little or no room for their own creative input into their teaching practice. Syllabuses, textbooks and teacher support material are extremely important in helping to structure and support learning but they also need to allow for the teacher's professional creativity. Teachers can support creativity and innovation by:

1. **Role modelling creative habits**
   Nothing is more important than the teacher exemplifying the habits, behaviours and thinking they want students to demonstrate. They need to exemplify creative traits such as curiosity and the development of creative skills (see thinking routines later in this chapter).
2. **Appreciating the critical importance of questions, both their own and those asked by students**
   Considered later in this chapter.
3. **Treating mistakes as learning opportunities and encouraging learners to take sensible risks in the classroom**
   Encouraging learners to take 'sensible risks' in their work is important for building up their creative confidence. It is important that this takes place in a supportive environment, and that the teacher and learner have discussed what boundaries are acceptable in their context. It is also important to set some ground rules in collaboration with learners.

4. **Giving learners sufficient time to complete their work**
   Sometimes ideas need time to develop before becoming valuable. Giving learners the scope to come up with their own ideas can be challenging for both teachers and learners. Learners will need time to think and work independently of the teacher. Delay judgement of learners' ideas until they have had time to work them out properly.
5. **Scaffolding tasks carefully to provide the appropriate level of challenge**
   Ideally, a teacher should try to design tasks that help the learner to cross over into this area by 'scaffolding', or supporting them at first, and then withdrawing support so that the learner can increasingly achieve the task on their own.

Even a small change in teaching approach can bring about a change in a learner's creative disposition. If learners start to see that there is not always 'one right answer' to many questions, both in school and in life, then their creative confidence will grow. The most important thing of all is for learners to lay the foundation of their personal creative abilities, on which they will build throughout their lives

Incorporating creativity into classroom practice across the curriculum

Problem solving and enquiry are at the heart of learning. By definition, they require learners to think hard using their existing understanding to engage with the question or problem at hand and work out solutions.

Pitching questions or problems at exactly the right level to stretch student thinking, and providing just enough support, is the mark of a good teacher. How teachers present problems and questions will vary depending on student age, the local culture, the discipline being studied and many other factors. There is a place for a wide range of approaches including whole-class instruction as well as individual and group collaborative work, and some variety is important.

Sometimes it is incorrectly assumed that creativity occurs best in group work with the teacher acting as a facilitator. In fact, direct instruction involving the whole class can encourage creativity as long as the classroom culture is supportive and the class focuses on powerful questions and problems. It is important to note that direct instruction, well done, is identified in John Hattie's work (2009, p. 204) as a highly effective approach to teaching and learning. Direct instruction should involve a highly skilled active process in which the teacher engages and challenges student thinking, responding quickly to student thinking as it emerges. Discussions are focused on important concepts and ideas with questions from students. The teacher stimulates thought and encourages new ideas and new ways of thinking. Both students and teachers see errors as guiding what still needs to be learned rather than signalling failure.

Enquiry-based learning is often associated with student-led projects. In this context learning involves a teacher and/or learners setting a meaningful problem or question which challenges and extends learners' understanding over an extended period of time. Projects could be within one subject or combine two or more subjects. The problems or questions may be open ended, complex and multi-faceted. Projects often culminate in learners doing a presentation of their work to the rest of the class, but the 'product' created could be something that is made public such as a blog, website, exhibition or magazine. By its nature, project-based learning involves learners using reflective, creative and critical thinking skills in collaboration with others.

For project-based learning to work well it is important that the learning objectives are clear, supportive of the broader curriculum, and the teacher plays an active role in supporting the development of student understanding. This may involve the teacher standing back for long periods, allowing students to explore and experiment and think through the problem, but they need to be active in challenging student thinking and bringing learning to a productive conclusion. Cambridge Global Perspectives (considered in Chapter 7) provides well-structured examples of this approach.

One advantage of enquiry-based learning is that it provides an opportunity for learners to collaboratively explore a question or problem from multiple perspectives using lateral as well as linear thinking. Edward De Bono is credited with inventing the concept of lateral thinking and has developed a number of approaches including the Six Thinking Hats (1993, p. 54), a strategy that can be used to help learners at all levels and in any subject, to think about a question from multiple perspectives (see De Bono in the Resources section).

Using questions to trigger creative thinking

Socrates (470–399 BC), popularised through Plato's writings, believed the best form of teaching was through using skilled, disciplined questioning to deeply explore ideas resulting in improved understanding. This technique has become known as 'Socratic questioning' and is a fundamentally important teaching and learning approach in all disciplines. A good question, from the teacher or student, has the power of making student thinking visible and is a natural part of the ongoing feedback loop in classrooms between students and teachers, helping to guide the instructional process.

On average, teachers ask between 300 and 400 questions a day (Leven & Long, 1981, p.29). If a teacher carefully plans the type, wording and delivery of questions that they are going to ask in a lesson, research shows that the quality of learners' thinking and responses will improve (Budd Rowe, 1986, pp.43–50). Questions that stimulate responses that require complex mental processing can encourage creativity. What if...? and Why…? questions tend to stimulate creative and critical thinking, especially if followed by more questions that probe and encourage the learner to go further (Kazemi, 1998, pp.410–414).

Asking learners to think of their own questions is a particularly valuable activity. Guy Claxton (cited in Scales, 2013, p.250) points out: 'Asking good questions is the basis for becoming a successful learner. If children aren't asking questions, they're being spoon-fed.' A learner formulating a question can illuminate their current thinking, helping to guide instruction, as well as being a creative activity in its own right. Encouraging learners to ask questions can:

- develop their curiosity about the subject, helping with engagement
- stimulate learners to 'think hard' about a topic
- consolidate a learner's understanding of the material
- enable learners to look at a topic from different perspectives
- clarify a goal or plan for their own investigations
- inspire them to want to find out the answer.

One line of questioning that can encourage creative input is 'possibility thinking'. This requires learners to explore ideas and use their imagination to generate lots of possibilities. If a teacher regularly asks questions that have more than one answer during lessons, this can develop an atmosphere where learners feel that their unique contributions are welcomed and valued. This helps learners to develop their creative disposition as described earlier in this chapter.

Table 12: Examples of possibility thinking

Consider asking your learners questions that have more than one possible answer

In maths: 'How many ways can you find to make 24 using any mathematical operation?'

What was the question?
'The answer is… 1989, … what was the question?'

Give learners a word or number that could be the answer to many different questions in your subject. For example, the question could be:

- When did the Berlin Wall fall?
- In which year did South Africa start to dismantle the apartheid system?
- In which year did the Cold War end?
- Which year saw the dissolution of the Soviet Union?
- Which year saw the end of the Soviet Union's occupation of Afghanistan?
- When did Tim Berners-Lee produce the proposal that led to the World Wide Web?

Thinking routines, introduced in Chapter 3 (see Harvard University's Project Zero 'Visible Learning' resources at the end of the chapter) can be helpful in generating questions and nurturing critical and creative thinking skills, emphasising the use of discussion and collaboration in the classroom. One example of a thinking routine is below in Table 13. This can be adapted to almost any subject or context to prompt thinking and questions from learners.

Table 13: Harvard Project Zero – Artful thinking routine: See/Wonder/Connect

This thinking routine is useful to trigger questions and thinking about a topic for which you have a related photograph, artwork or object. For example, photographs of a specific place for a geography case study. **See**: Show learners an artwork, photograph or object that relates to your subject. This could be in an art gallery, or the classroom. **Wonder**: Brainstorm a list of 3–5 questions about the artwork. Use these question stems as starters: I wonder… Why… What are the reasons… What if… I am puzzled by… How would it be different if… What if we knew…? If I could interview the artist/maker, I'd ask… **Connect**: Compare the artwork/object/photograph to others you've seen. How are they similar? How are they different? The questions that learners formulate should be recorded and displayed if possible, to show the value that the teacher places on them

Mathematics, creativity and innovation

'Creativity is what maths is all about… We're coming up with some completely unexpected patterns, either in the reasoning or the results… We're thinking in terms of beauty and creativity, but the outside world thinks of us like a computer' (Sir Andrew Wiles, who proved Fermat's Last Theorem).

The Fields Medal is the mathematical equivalent of the Nobel Prize, awarded to mathematicians who have made major contributions to the field. In 2014, it was awarded to a successful young mathematician called Manjul Bhargava. His achievement was to simplify a very complicated mathematical 'proof' from the 18th century into a few lines. He was inspired by seeing a Rubik's Cube in his room, and imagined that the numbers that he was working on were applied to the corners of the Rubik's Cube. 'If you think about things the way someone else does, then you will never understand it as well as if you think about it your own way,' he said about the creative process that led to his breakthrough.

That mathematics is still being created often comes as a surprise to most students, and many teachers. Their perception is that mathematics is the one subject in which you know conclusively that you have the right answer. Indeed, many students prefer mathematics over other subjects precisely because of this. The misconception arises because they believe that calculation, and solving routine problems such as those assessed in qualifications, is mathematics. In fact the whole point of learning mathematics is to solve problems, including those which are non-routine, and that of course involves thinking creatively.

While Fields medallists – who are certainly exhibiting Big-C creativity – come along only once in a while, there are plenty of opportunities in mathematics lessons to support students in becoming creative mathematicians of the small-c or mini-c variety. Indeed, a mathematics scheme of work that does not include opportunities for students to think mathematically – to explore, discover, imagine and produce some mathematics which is original to them – needs serious adjustment.

So what does creativity look like in the mathematics classroom?

Firstly, creativity is considerably inhibited if students do not have an adequate mathematical toolbox. In other words, they need to have a reasonably secure base of

knowledge and skills to draw on. However, creative activities should not be restricted to those who are already good mathematicians. The very act of being creative can itself enhance students' understanding and fluency, so such tasks are suitable for all.

To support students in being creative, teachers offer tasks and activities which allow students to:

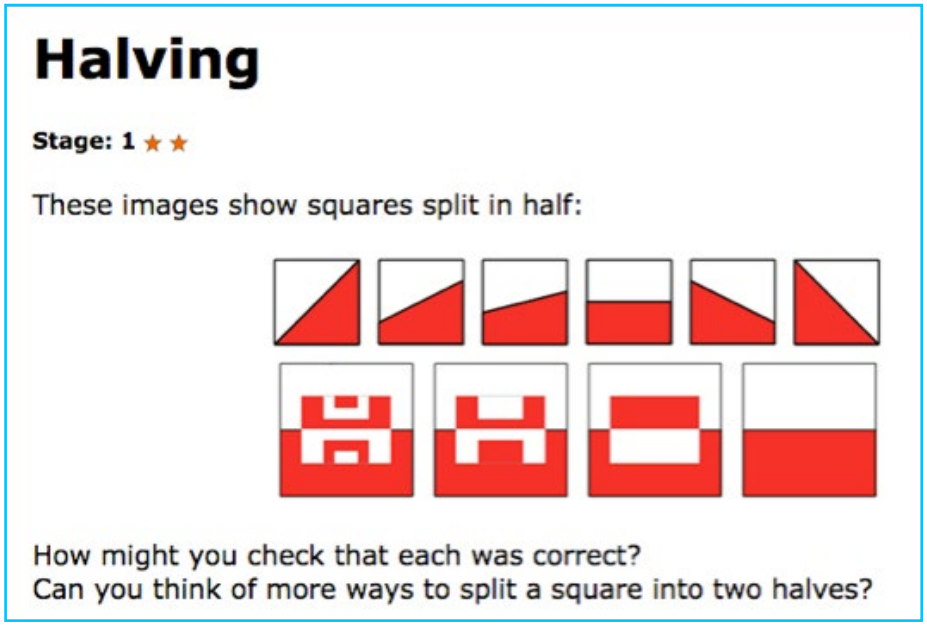
1. **Find multiple ways of solving a problem.**
2. **Ask their own questions as well as answering the teacher's.**
3. **Discover relationships, patterns and make connections that are new to them.**
4. **Conjecture about the results of making changes.**

The NRICH project (**www.nrich.maths.org**) offers 'low threshold, high ceiling' tasks. These are open-ended tasks which everyone can begin, but which have enough challenge built into them to occupy the most confident and competent, so they are suitable for whole-class teaching.

Next are four examples of such tasks.

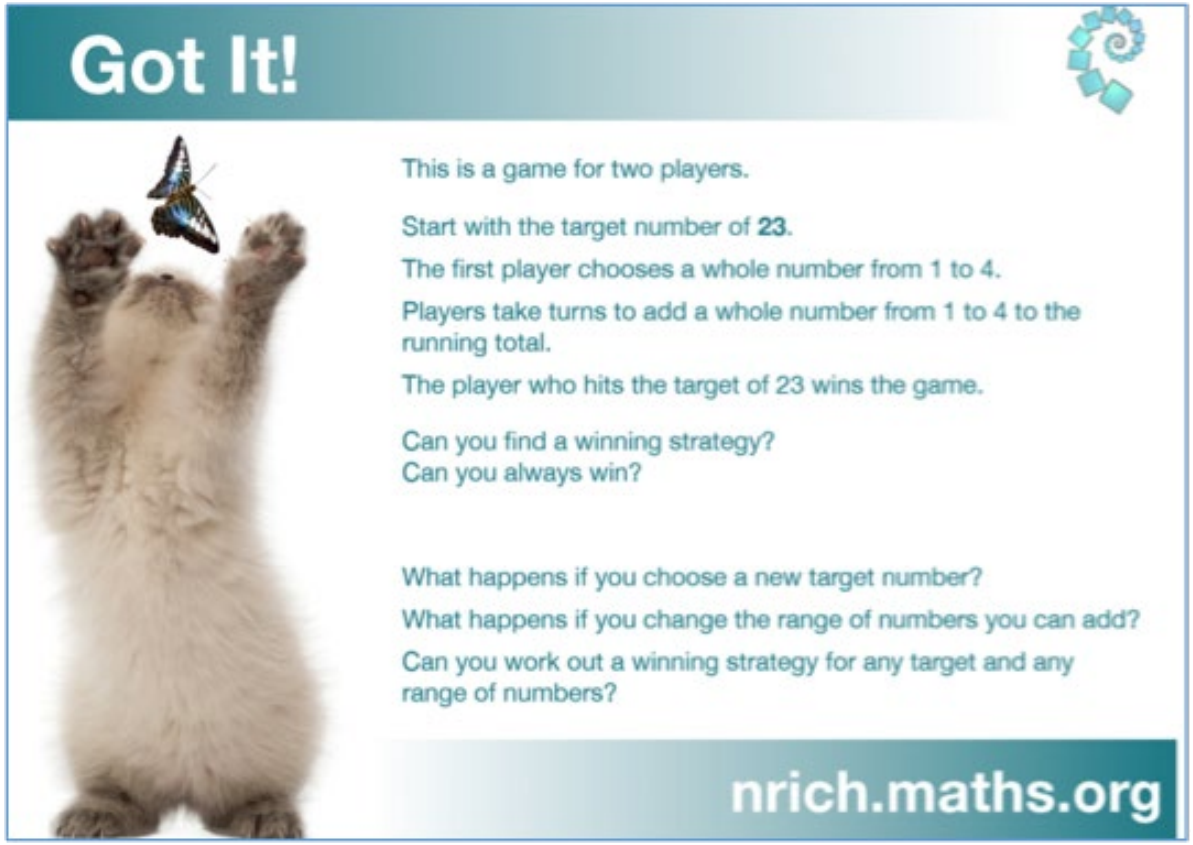
1. Finding multiple ways of solving a problem

This activity, recorded on squared paper (with square size appropriate to age of student) supports the concept of equivalent areas. The examples offered show identical halves and the majority of students will be able to replicate this idea. However, creative individuals will look for examples where although the areas are equivalent, the shapes of the halves are not the same. This is an example of students devising their own solutions and simultaneously extending their idea of a half, and of area. To see how students solved this, visit **nrich.maths.org/1788/solution**



2. Ask their own questions

The mathematics in Got It! is quite trivial – adding small numbers. However, to 'solve' the question, students have to work out how to win. This requires asking the right questions and trying out lots of strategies. The question includes some 'high ceiling' hints such as changing the target – but students have to choose wisely if they are to succeed. For an interactive version visit **nrich.maths.org/1272**



3. Discover relationships

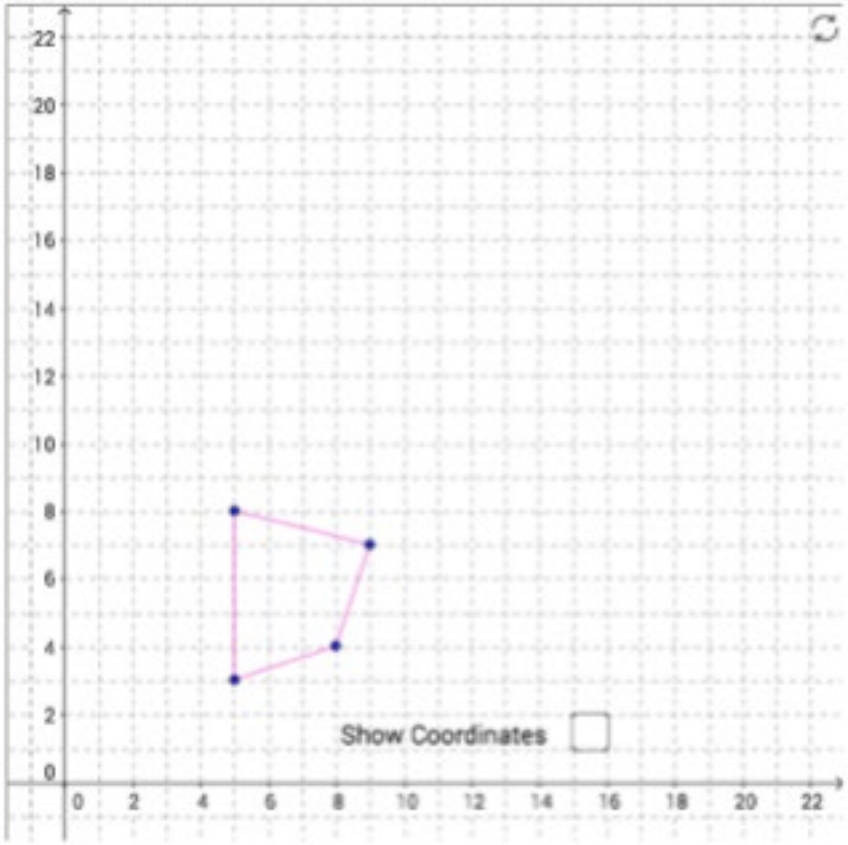
This interactive task allows students to play around with the characteristics of squares, using visual clues initially. To solve the last question, they have to focus on the coordinates and are then confronted with the idea that points in certain relationships have coordinates that fit a pattern. This activity highlights the power of digital technology to provide instant feedback – a hugely important part of working creatively. Visit **nrich.maths.org/10733** to find out more.

Coordinates of Corners

Stage: 3 and 4

This resource is part of "Dotty Grids - Exploring Coordinates and Vectors"

Move the dots below to make some squares. Can you make a variety of squares whose sides are not parallel to the axes?



If you have a set of four coordinates, is there a quick way to decide (without drawing) whether they form a square?

4. Conjecture about making changes

White Box (**nrich.maths.org/7007**) models the scientific process of working out the structure of atoms and molecules. It is an ideal activity to support students in making conjectures or hypotheses, as they work systematically to change the layout, record their findings and deduce what is happening. Where must the triangle be to produce that result? What if I move it to…? As with 3 above, these modelling-type questions would not be possible without immediate feedback.

A proficient mathematician therefore needs not only a thorough knowledge and understanding of the subject matter, but they also need creative thinking skills to be able to manipulate that knowledge and to become truly innovative.

White Box

Stage: 2, 3, 4 and 5 ★

The White Box contains a number of filled triangles.

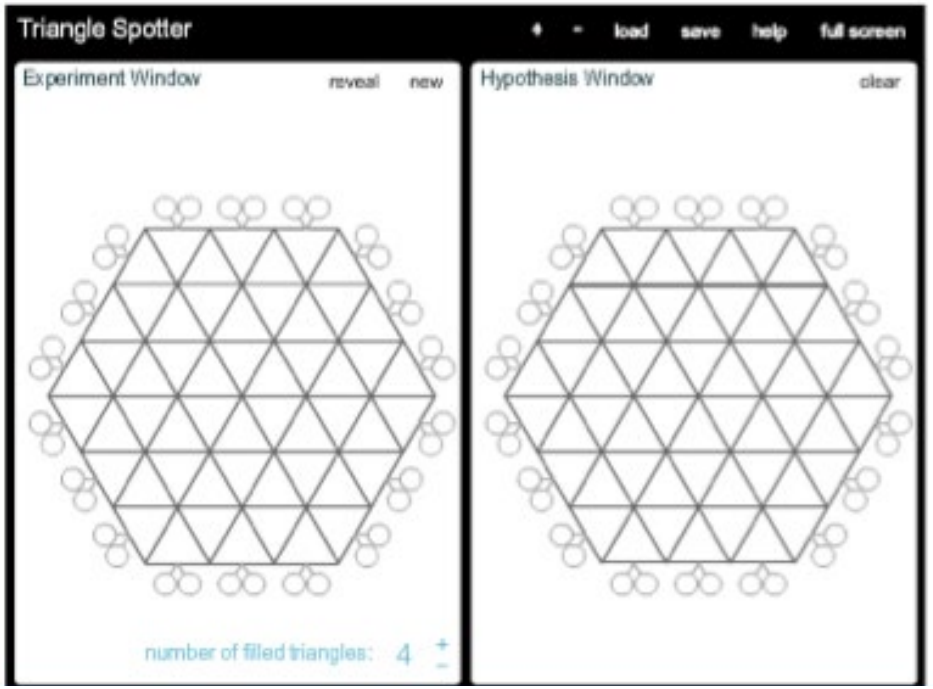
Your challenge is to find the locations of those filled triangles in the grid.

You can fire rays into The White Box and observe where the rays exit using the Experiment Window.

Some rays will pass straight through the Box but some will be deflected by the filled triangles.

You can use the Hypothesis Window to test your ideas. Clicking on a triangle once marks the triangle as empty, clicking again fills it.

FULL SCREEN VERSION



Science and creativity

Science is not only a body of knowledge to be learned and understood, it represents a powerful method in identifying and solving problems with a significant creative component. Well-planned, structured enquiry is fundamental to science teaching as it reflects the scientific method: curiosity based on existing knowledge, hypothesis formulation, systematic observation, measurement and experimentation leading to new insights. A deep understanding of the scientific method provides powerful knowledge to students, preparing them for further study in science and helping them to understand applications beyond science. One simple example of enquiry-based learning in science that offers the potential for creative thinking is in Table 14, below.

Table 14: An example of a low-tech tinkering activity: Marble Machines (Winterbottom et al, 2016, p.14)

Cambridge teachers exploring the idea of scientific tinkering

In this activity the participants choose from a wide selection of recycled materials and low-tech tools (for example, scissors, sticky tape, cardboard, elastic bands, pipe cleaners) to achieve the goal of 'getting a marble to move from the top of the pegboard to the bottom as slowly as possible'. The imposed condition 'as slowly as possible' is important. Without it, it's too easy, and the goal is too closed.

Through their explorations, participants may engage in 'engineering' (for example, working out the best materials to create a funnel), 'making' (for example, building a run from cut-up tubes) and 'tinkering' (playfully experimenting with the different materials as they develop their thinking and set new short-term goals).

In a science lesson, this could be a starting activity to help learners to encounter ideas about forces and motion before any of them have been taught the ideas theoretically. By imposing the 'as slowly as possible' condition, learners use intuitive ideas about friction. They also use ideas about rotational movement, linear movement, acceleration and velocity. When they have misconceptions about those topics, this activity can help expose them, and enable the learners to discover that they have misconceptions.

However, most of the time, this is not used in the context of a specific topic in science. It is more there to foster skills, and understanding of the nature of science, including hypothesis setting (albeit informally), testing, controlling for variables and collaboration.

What can we learn from the arts?

Arts subjects such as art and design, music, drama and dance are often associated with creativity and innovation. A broad and balanced curriculum (see Chapter 2) recognises that encouraging the arts can help students to develop their own creative voice and creative thinking skills. Studying an arts subject can also build learners' self-confidence as they feel valued for their unique contributions and talents. When encouraging creativity across the curriculum, it can be useful to look at the ideas and techniques that underpin the teaching of creative subjects such as art, drama and music.

Learner autonomy: Arts subjects can be popular with learners because of the perceived high level of learner choice that is involved. Learners often work on projects that they have devised themselves, according to their own interests and passions. Unique and original work is particularly valued, in both informal and formal assessments. When learners take control of their work in this way, their levels of intrinsic (internal) motivation tend to increase (Craft, 2005, p.56).

Valuing uniqueness: Every learner's outcome will be different in arts subjects. The idea of there being 'no one right answer' is deeply embedded in both the teachers' and the learners' approaches. Although other subjects have more fixed subject matter, it is important for students to learn that there is often more than one correct answer or more than one way to arrive at an answer.

Experimentation and play: In all arts subjects, there is an emphasis on experimentation and 'play'. An art teacher will introduce a technique or material, for example acrylic paint, and learners try it out. This may initially involve copying examples and practising. Boden (2001, cited in Ferrari, Cachia & Punie, 2009, p.19) describes this as 'exploratory creativity', and likens it to a jazz musician learning to improvise based on a defined set of chords or scales. Having developed some degree of skill, learners can then start to experiment and push the boundaries of the material or technique. They may choose to combine it with another technique or idea to produce something that is original to them. Boden calls this 'combinatorial creativity' – the generation of new ideas by combining or associating existing ideas.

There is a role for experimentation and play in all disciplines so that students learn to use their imagination and develop engagement. As in arts subjects, this must be balanced with, and be supportive of, skill development so that it supports students' basic literacies.

Looking at and discussing artworks: The study of artworks is not necessarily limited to art or art history lessons. Images of artworks can be used to prompt thinking in any subject area. Teachers can use carefully chosen artworks to prompt discussions and deeper critical thinking about a topic. Visual Thinking Strategies (VTS), developed by Yenawine (2014, p.25; see the Resources section) uses art to help learners of any age to develop their visual literacy, thinking and communication skills, and is an excellent resource.

Journals, notebooks and sketchbooks: Keeping a notebook, sketchbook or journal is an essential part of an art and design education. All the creative skills can be practised through the discipline of keeping a record of a learner's observations, ideas, reflections and collections. By recording and collecting a wide range of information, a learner can then start to cultivate creative connections between different elements and come up with more unique and original ideas. Notebooks and journals have been used by many great creators, such as the poet Lord Tennyson, who recorded fragments of thought and then generated connected words and images which led to his poetry (Michalko, 2001, p.58). Charles Darwin kept detailed journals on his travels to the Galapagos Islands, and his journals contain a record of his tentative diagrams of the branching system on which he eventually based his theory of evolution. Guy Claxton (2006, p.353) recommends encouraging learners 'to keep a commonplace book… in which they keep scraps of overheard conversation, images, quotes, fleeting thoughts that didn't go anywhere… as most creative writers, scientists, composers do'.

The value of failure: The arts, perhaps more naturally than other subjects, accept and celebrate failure as a learning opportunity and understand that it is an inherent part of the creative process. As West-Knights (2017, p.49) points out: 'One of the mainstays of drama classes… is the notion that mistakes are OK, as long as you are trying things out.'

Peer review and feedback: Peer review sessions (sometimes called group critiques) are commonly used in art and design as a method of informal interim assessment. Learners present their work to small groups of their peers and receive constructive feedback. The process is carefully scaffolded by the teacher, who leads initial sessions, modelling the types of questions and comments that are appropriate. When successful, peer reviewing helps learners to build independence, gain insight into their peers' working and thinking processes, and develop confidence in themselves as creative individuals.

Making connections: mind mapping

As illustrated in figure 6 on page 58, mind maps (sometimes called concept maps or spider diagrams) are a flexible and powerful tool for representing information and nurturing creative and critical thinking. Originally popularised and developed by Tony Buzan in the 1970s, mind maps are designed to 'harness the full range of cortical skills' (Buzan, 1986, p.45) by using key words, colour, images, number, logic, rhythm and spatial awareness.

Mind maps are essentially diagrams that visually organise information. They normally consist of a central concept, which is expressed with a key word or short phrase. Related ideas branch off from this, spreading across the paper, which is usually in landscape format to give the optimum space for ideas to be written. Each main branch that emerges from the central theme can then branch out further to related sub-sections.

The theory of semantic network models (Collins & Quillian, 1969, p.240) helps to explain why mind maps are effective. Each learner has their own unique understanding of any subject at a particular time based on their own personal associations and connections. The act of creatively constructing mind maps requires students to think hard about what they are learning and to build new connections. Learners will find it easier to remember information by building their own personal representation of understanding. It is impossible to create a mind map without active engagement and thinking through the construct being mapped. Building up a large amount of information on a page also encourages creativity. Learners can make connections between topics, which they may not see while studying a dense block of text. Mind maps can be used in a number of ways including:

- Note taking. The act of creating a mind map requires chunking of information and concepts, relating them to each other. This can be helpful both in developing understanding and helping to memorise information. It makes the process of note taking active rather than passive. At the end of a unit, a teacher might ask learners, individually or collaboratively, to create a mind map of what they understand about a topic that has been covered. Many learners find mind mapping a very useful technique when revising for exams, as the process of reformulating their notes into a new structure is in itself a memorable activity.
- Planning essays, presentations or projects. By using key words, learners can fit large amounts of information onto one page, allowing them to get an overview of a topic and to plan information strategically.
- Clarifying, analysing and re-defining problems or questions. This helps learners to uncover new perspectives, to build higher-level thoughts and to develop understanding, analysis, synthesis and evaluation.
- Making connections. This supports the development of holistic and disciplinary understanding through connecting ideas from different topics or different subjects.

Mind maps are an extremely versatile and accessible approach to help visualise and understand material. Many learners, including those who have dyslexia or other learning difficulties, find mind maps very useful, and they can be used to support learning in all disciplines. Research by Park and Brannon (2013, pp.2013–2019) found that training learners to use visual and spatial representations significantly improved their performance in mathematics, even when undertaking numerical problems. Research has shown that mind mapping is more effective as a means of knowledge retention and transfer than attending lectures, participating in class discussions or reading text passages alone (Nesbit & Adesope, 2006, p.434).

For more information on mind maps see the references and resources at the end of this chapter.

Assessing innovation and creativity

As argued already in this chapter, the outcomes of creative processes are incorporated naturally into teaching and learning. Teachers can assess them when students complete an assignment or task and have demonstrated creativity.

Because creativity is a process inherently linked to reflection, it is often valuable to assess progress at appropriate points in the journey. This needs to be done sensitively. If learners or teachers are too critical of ideas during the ideas generation phase, they may find that they dismiss all their ideas and do not have anything to work with.

Creativity lends itself to self-evaluation, peer evaluation, process/progress learning diaries (sometimes called process or progress journals), portfolio assessments, blogs, presentations and exhibitions. As Rachel Logan, Product Manager for Art and Design at Cambridge explains: 'We are assessing how well they have thought "around" a problem, not necessarily how well the solution works.' She adds: 'It's vital that learners have critically evaluated their outcomes, but in the end it's mostly about the process that they went through to get there.'

Ellis and Barrs (2008, p.78) have developed a generic rubric to informally assess creative learning. Rubrics are designed to clarify criteria and standards against which students' work can be assessed. This focuses on the processes involved in creative work, including investigation, skills, discussion, evaluation and reflection. The rubric is intended for use in a primary classroom, but could be adapted for any level.

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Resources

Questioning

Rothstein, D. & Santana, L. (2015). *Make just one change: Teach students to ask their own questions*. Cambridge, MA: Harvard Education Press.

This practical teachers' guide describes the 'question formulation technique' as developed by the authors over several years of working with learners across a range of socio-economic backgrounds, including bilingual learners. The book goes through the strategies step by step and gives examples of how teachers of different subjects have implemented the technique.

Essentially, the strategy is to prompt learners' curiosity with a 'question focus' which could be an image, statement or audio-visual stimulus. Learners then create questions through divergent thinking routines. They then prioritise and improve these questions with help from their teacher. Finally, a range of possible next steps are suggested as to what learners might do with the questions. These include 'do-now' activities, identifying topics for further research and investigation, preparing for tests, providing formative assessment information for teachers or preparing a research agenda for the next unit of study.

Educating for Creativity: Level 1 Resource Guide

www.creativeeducationfoundation.org/wp-content/uploads/2015/06/EFC-Level-1-FINALelectronic.pdf

This guide from the Creative Education Foundation gives lots of useful tips about how to encourage your learners to solve problems creatively. The creative problem solving (CPS) process is based on the Osborn-Parnes CPS model. There are descriptions of brainstorming-type activities for cross-curricular projects. The ethos behind this model is to encourage an environment in which creativity and innovation can thrive using a range of techniques and strategies. The authors aim to nurture creative skills which will become an integral part of learners' work and life in future.

Buzan, T. (1996). *The Mind Map book*. New York, NY: Penguin.
One of many publications by Tony Buzan that explores the possibilities of mind maps and explains how they are best generated.

De Bono, E. (1993). *Serious Creativity: Using the Power of Lateral Thinking to Create New Ideas*. USA: Harper Business.
Although primarily aimed at a business market, this book contains very detailed descriptions of how to implement Edward De Bono's many lateral thinking tools, including Six Thinking Hats, Provocations, Random Input and more. There are also suggestions for how to run training or set up a creative thinking session, which could easily be adapted for use in schools.

Online resources from Edward De Bono
Edward De Bono's CoRT thinking tools are described in this resource, along with many other ideas for using questions to trigger critical and creative thinking: **www.nsead.org/downloads/Effective_Questioning&Talk.pdf**

Instructions and descriptions of De Bono's CoRT thinking tools with examples: **http://elearnmap.ipgkti.edu.my/resource/gkb1053/sumber/CoRT1-4.pdf**

Simister, C. J. (2009). *The Bright Stuff: Playful ways to nurture your child's extraordinary mind*. Harlow: Prentice Hall LIFE.

This book contains a large number of creative thinking ideas that could be incorporated into all levels of teaching.

Craft, A. (2000). *Creativity across the Primary Curriculum: Framing and Developing Practice*. London: RoutledgeFalmer.
This is an inspiring read, practical but informed by theory and research. Anna Craft explores core principles and the different subjects, and considers ways in which teachers can develop a more 'creative mindset' towards the curriculum and pedagogy.

www.amazon.co.uk/Unlocking-Creativity-Teaching-Curriculum-Teachers/dp/1843120925

Fisher, R. (2005). *Unlocking Creativity: Teaching Across the Curriculum: A Teacher's Guide to Creativity Across the Curriculum*.
A comprehensive guide to incorporating creative approaches into your lessons. It has sections on specific subjects including maths, creative writing, drama, science, design technology, geography, music, art and religious education.

Scoffham, S. (Ed) (2004). *Primary Geography Handbook*. Sheffield: The Geographical Association.
This subject-based handbook for teachers has a wealth of tried and practical examples of creativity applied to geography. Chapters on 'Young geographers', 'Geography, creativity and place', 'Geography and the emotions' and 'Making geography fun' show how creative teaching and promoting creative thinking in children is central to a subject not usually thought of as creative.

Yenawine, P. (2014). *Visual Thinking Strategies: Using art to deepen learning across school disciplines*. Cambridge, MA: Harvard Education Press.
An in-depth explanation of visual thinking strategies (VTS) as mentioned in this chapter. This is a teacher's guide to the VTS project, which started as a collaboration between the education team at the Museum of Modern Art, New York and academics at Harvard University. It includes lots of examples of how to implement the strategies as well as written records of typical conversations in classrooms where VTS is being used.
www.visiblethinkingpz.org/VisibleThinking_html_files/03_ThinkingRoutines/03d_UnderstandingRoutines/ThinkPuzzleExplore/ThinkPuzzleExplore_Routine.html
This site contains excellent resources explaining a wide range of thinking routines developed by Harvard Project Zero, including this 'think, puzzle, explore' thinking routine. These activities are easily adaptable to any learning situation for any age. There are also videos of the routines in use in classrooms.

Compass Points thinking routine from Harvard Project Zero:
www.visiblethinkingpz.org/VisibleThinking_html_files/03_ThinkingRoutines/03c_Core_routines/CompassPoints/CompassPoints_Routine.html

Project-based learning resources

www.bie.org/resources
The Buck Institute for Education, USA. This site contains resources and case studies on successful project-based learning.

www.hightechhigh.org/htm/projects
High Tech High in San Diego, USA. Examples of learner projects with learning outcomes and teacher reflections.

https://jennyluca.com/2012/10/02/project-based-learning-giving-it-a-go-in-an-english-classroo
This blog explains one English teacher's experiences implementing project-based learning in her English literature classroom, studying Romeo and Juliet.

www.bie.org/object/document/english_learner_scaffolds_for_pbl
English literature project-based learning scaffolding guide.

Tinkering

www.museoscienza.org/tinkering-eu/download/Tinkering-A-practitioner-guide.pdf
This document explains the background behind the tinkering movement, and gives detailed guidance on how to design and implement tinkering activities. Although the examples are design-technology based, they could be adapted for science or art lessons.

www.raeng.org.uk/education/schools/teaching-and-learning-resources/curriculum-resources
The Royal Academy of Engineering (UK) offers a range of resources for teachers of STEM subjects (science, technology, engineering and maths). The lesson plans include topics such as 'Desert', which looks at how people and animals survive

in the desert. Activities include learners designing a 'fog catcher' based on their understanding of condensation. It includes handouts and resource lists.

Creative thinking for school leaders

This is a more generalised guide to creative thinking, aimed at school leaders:
Kampylis, P. & Berki, E. (2014). Nurturing creative thinking. International Academy of Education, UNESCO.

Creativity through making

https://www.gse.harvard.edu/news/uk/14/10/learning-making

https://www.weareteachers.com/making-matters-how-the-maker-movement-is-transforming-education

Rubrics for creativity

https://ccgiftedcollaborative.wikispaces.com/file/view/6+Creativity.pdf

http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf