EDUCATION: FUTURE FRONTIERS

A conversation starter

Thinking for the future – preparing students to thrive in an AI world

"Thinking skills, or cognitive skills, are, in large part, things you do with knowledge. Things like analysing, evaluating, synthesising, inferring, conjecturing, justifying, categorising and many other terms describe your cognitive events at a particular functional level."

Ellerton, 2015

The NSW Department of Education's Education for a Changing World project is investigating implications of global change and the rapid rise of artificial intelligence (AI), automation and related technologies and identifying strategies for enhancing education.

This conversation starter briefly explores how higher order, deeply embedded thinking skills form a crucial bedrock for student learning and success. These thinking skills set the foundation for lifelong learning and support students' agency and capacity to engage with increasing complexity. Strong thinking skills are the building blocks that enable students to better know, influence and shape their world.

There is a sizeable list of skills that may be considered 'thinking' skills. A broad consensus embraces skills of critical thinking, problem solving and creativity, computational thinking and data facility, ethical reasoning and metacognition. While these skills can operate autonomously, they most often are used in an interrelated web of skills, understanding and application. Since application of learning relies on embedded thinking skills they demand a significant focus in education.

This paper provides a brief overview of key thinking skills that are commonly referred to in the Australian and international curricula including: critical thinking; creative thinking and problem solving; computational thinking and mathematical logic; ethical reasoning; and metacognition, or 'thinking about thinking.'

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The importance of '21st century skills' in schools

The debate about what skills and knowledge are needed for the 21st century has been given renewed focus with the release of the Australian Government's *Review to Achieve Educational Excellence in Australian Schools* ('Gonski 2.0') and the NSW Curriculum Review. Recent media headlines such as 'Hard facts v soft skills: a new front in the education wars,' 'Shift to a "radical" curriculum: push to focus on contentious 21st-century skills in the classroom,' and 'Trendy school fads are no substitute for knowledge' reflect the varied, and at times opposing opinions that are fuelling this debate.[1]

Most 21st-century skills frameworks, including the Australian and NSW curricula, already firmly embed and value the types of knowledge and skills that students will need to learn, master, and apply to succeed in a rapidly changing world. The rapid expansion of AI and machine learning has led many to conclude that thinking skills, combined with discipline knowledge, will become even more highly prized.

In this conversation starter, we look at why these skills are so important in a complex and uncertain world and raise a number of important questions, ranging from whether there is an established consensus on what these skills entail (crucial if we're to identify how to teach and assess them) to broader questions of how such skills should be taught, extended and applied throughout schooling.

Engaging in an AI world

Children who began school as the 21st century dawned have now left their schooling years behind. Already another generation of school students is well into their classroom lives, and they will live and work across the remainder of this century and, for some, into the century beyond.

Their world will be more complex, changing, and filled with opportunity and challenge. It will demand that educators ensure students emerge from their schooling with both deep knowledge and excellent skills to understand, interpret and shape their world – in the workplace, community and beyond. Constantly changing information and knowledge certainly requires currency in curriculum and teaching practice – and underscores just how important and enduring those high-quality thinking skills that permit constant learning will be.

If we look specifically at technology and the advent of AI and machine learning, students will need to become not just skilled in *using* technology, but knowledgeable about *how it works.* They will need to understand the nature of algorithms and their operations, perhaps to become computer programmers, but also because this understanding is an important ingredient in shaping how these technologies will be deployed. We live in an age where algorithms seem to take on a life of their own, where a driverless car will be able to make trillions of mathematical operations per second, and where even Google's CEO confirms he cannot precisely say how the search engine's computational DNA works.[2]

Yet technology is not a force of nature; it reflects the decisions of its designers and the contexts in which it operates.

So students will need to know much more than coding in an AI-augmented world. They will need to know when they can rely on a machine's decision-making power, and how human bias can be coded into machine learning, resulting in the production of faulty data logic that may be used to inform decisions.[3] Examples already abound, including the highly publicised role of Facebook's platform allegedly swaying the recent US elections, the use of algorithms to personalise content feeds resulting in a narrowed exposure to diverse views, the racial bias inherent in the COMPAS algorithm used in the US to predict criminal reoffending, and search engine algorithms advertising high income jobs to white males in preference to females.[4]

Such use of algorithms confers power and authority on the software designer and owner and raises broad and significant issues. Education must therefore address the competency of students' computational thinking and also develop their capacity for sophisticated ethical reasoning, to identify potential manipulation, and to shape the operations and impact of this powerful technology.

Equally important, strong thinking skills will help young people develop their sense of confidence and agency even in domains where they may not have expert knowledge but where they may contribute.

What thinking skills make a difference?

Industry calls for greater teaching of the widely applicable set of thinking and entrepreneurial skills most valuable for enterprise and employment. National committees and think tanks around the world increasingly devote considerable resources to addressing this set of requirements. Yet specific priorities can diverge depending on who is being asked. The 2018 QS Global Employer Survey, for example, reveals that young people highly value the thinking skill of creativity (ranked first among graduates) while employers placed creativity ninth in importance, behind skills such as resilience, technical skill and data analysis.[5] Nevertheless, thinking skills consistently appear in lists detailing the current and future global skill-sets most desired by industry, and their utility extends to economic forecasts at the national level.[6]

What follows is a brief overview of key thinking skills, intended to stimulate conversation.

Critical thinking

The Australian Curriculum identifies critical thinking as being "at the core of most intellectual activity that involves students learning to recognise or develop an argument, use evidence in support of that argument, draw reasoned conclusions, and use information to solve problems." [7] This definition incorporates intellectual behaviours which are common to many other types of thinking skills, such as explaining, evaluating, analysing and hypothesising. Critical thinking is also classified as a general capability alongside creative thinking,

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>
> **Ellerton, 2015**

meaning that it is developed both across and within different subject domains.

Beyond this, critical thinking is defined in the academic literature as a collection of dispositions and skills underpinned by an open-mindedness to having currently held viewpoints challenged.[8] It is this capacity to actively seek out, and reflect on conflicting information, which arguably places critical thinking at the top of the thinking skills hierarchy in an AI-informed world. Critical thinking is about being disciplined and agile with thinking – and is a necessary capability across all content areas in a rapidly changing educational and contextual landscape.

Peter Ellerton, founding director of the University of Queensland Critical Thinking Project, argues that students need to have a strong grasp of content-rich knowledge to draw on if they are to tackle cross-disciplinary, diverse problems or novel situations. Equally important is the capacity for inquiry, self-correction based on reflection on other's arguments, and experience in applying critical thinking skills. Effective teaching of critical thinking therefore requires access to a flexible, content-rich curriculum, facilitated by highly reflective teaching.[9]

The design of the Australian Curriculum, in positioning critical and creative thinking as a general capability, also highlights their perceived importance across the eight key learning areas – English, mathematics, science, humanities and social sciences, the arts, technologies, health and physical education, and languages. This organisation may become increasingly important as, in all subject areas, students will need to sift through increasing amounts of data, understand the origin and intent of its source, make decisions as to its accuracy, and determine if they need to actively seek out additional information to objectively inform decisions they may make. Viewed in this light, critical thinking becomes an important 'cognitive sieve' for large bodies of information, and an essential skill for people to synthesise, analyse and evaluate information. As Ellerton notes: "No school could teach students all the knowledge they need to survive in a rapidly evolving society. But we could teach them how to think in a way that works for the knowledge they will learn in the future."[10]

> "Most people agree that the purpose of education is to prepare young people for the future. Like the present, we can expect the future to be highly uncertain. What teaching creativity offers to young people, is structured experiences with uncertainty so that they can develop the confidence and competence in resolving that uncertainty in creative ways."
>
> **Beghetto, 2018**

Creative thinking

The Australian Curriculum defines creative thinking as the ability of students "to generate and apply new ideas in specific contexts, seeing existing situations in a new way, identifying alternative explanations, and seeing or making new links that generate a positive outcome."[11] Robert Sternberg, a leading expert on theories of intelligence, expands on this definition stating that creativity is "not only the ability to produce work that is novel, high quality and appropriate, but that it also takes place in the interaction between persons and their environments."[12]

In other words, creative thinking is not just about the 'what' but also the 'how.' Creativity can embrace the arts or a brilliant, breakthrough invention – and also the innovation contained in a new process that leads to better outcomes. This open-ended nature of creative thinking is important for developing student engagement with new or changing circumstances.

Importantly, research has shown that explicit teaching can improve a student's capacity to respond creatively to diverse situations and stimuli even if there can be debate about the extent to which creativity is innate, teachable, domain-specific or transferable. In terms of explicit teaching, research carried out in Ontario universities found that most disciplines used explicit strategies for teaching creative thinking, such as collaborative project work, deliberately encouraging creative thinking, using the Socratic questioning method, challenging students to find alternate answers to existing problems, and brainstorming. A small number of disciplines in contrast also used the strategies of describing and emphasizing the importance of creativity to a field, modelling creativity, discussing examples of creativity, and reflection and journaling.[13] It is important to note that this study did not seek to answer the question of which teaching strategies are the most effective. Other explicit teaching methods found to be effective in teaching creative thinking include: supporting intrinsic motivation in place of competition and external reward systems; and actively encouraging student's belief in their own creative behaviour.[14]

Ronald Beghetto, Professor of Educational Psychology and creativity adviser for the Lego Foundation, highlights the pivotal role of the teacher stating: "one of the most direct and potentially influential ways that teachers can support the development of student's creative self-efficacy beliefs is to provide informative feedback on their creative potential and ability." Research has found this teacher behaviour to be the "strongest unique predictor of middle and secondary student's self-beliefs about their own creativity."[15]

On the value of teaching creativity, Beghetto comments: "Most people agree that the purpose of education is to prepare young people for the future. Like the present, we can expect the future to be highly uncertain. What teaching creativity offers to young people, is structured experiences with uncertainty so that they can develop the confidence and competence in resolving that uncertainty in creative ways."[16]

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> **Beghetto, 2010**

Beghetto also challenges educating institutions to reflect on assessment requirements placed on both teachers and students. He states “Classroom assessment practices can have a profound influence on creativity in the classroom. This is because assessments signal to students what is really valued and important.”[17]

Problem solving

Though not listed as one of the seven general capabilities within the Australian Curriculum, problem solving can be understood as a taxonomy of student behaviours – as opposed to a single behaviour – embedded within each of the eight key learning areas outlined by the Australian Curriculum. For example, within the early stages of maths, problem solving is described as a student's capacity to navigate “unfamiliar or meaningful situations” (F-2), and “plan their approach” (Years 3-6).[18] Within civics and citizenship, problem solving is linked with decision making, and the capacity to “recognise and consider multiple perspectives and ambiguities.”[19]

The OECD defines highly proficient problem solvers as students who demonstrate the ability to “systematically explore a complex problem scenario, devise multi-step solutions to take into account all constraints, and adjust in light of the feedback received.”[20] Australia performed well in the OECD PISA Assessment for creative problem solving (2012) and collaborative problem solving (2015). For complex problem solving, Australian students scored well above the OECD average and in the top ten in the world, with more than one in six students demonstrating the highest levels of problem solving.

Problem solving may also be defined in terms of complexity. A team of researchers from the University of Luxembourg, Thiemo Kunze, Matthias Stadler, and Samuel Greiff, define complex problem solving as “the process of solving problems that resemble real-life situations” in a way that is iterative and interactive.[21] Successful learners incorporate the capacity to apply both content knowledge and thinking skills to solve previously unchartered experiential territory (from the perspective of the learner), which may or may not sit within a specific domain.

Research also shows a strong relationship between the use of problem solving as an applied teaching and learning technique within a discipline, particularly when drawing on real-life problems, and student engagement, motivation, achievement, and retention of core ideas. This result may be further enhanced if problem solving occurs in a collaborative environment.[22]

Computational thinking and mathematical logic

Computational thinking can be defined as "the thought processes involved in formulating a problem and expressing its solutions(s) in such a way that a computer – human or machine – can effectively carry it out."[23]

Jeanette Wing, Professor of computer science, and Director of the Data Science unit at Columbia University expands on this, arguing that "computational thinking is really about tapping into the creativity of humans to understand problems and express solutions so that a computer can carry them out." Wing believes this skill will be necessary for almost every job role in the future.

There is a close alignment between thinking mathematically and computational thinking. Wing notes that strong computational thinking is particularly supported by skills in probabilistic and statistical reasoning. Given the rise of algorithmically-driven technologies, educational reform needs to carefully reflect on the relationship between certain mathematical skills and computational thinking. As Wing states: "We should emphasize not just discrete mathematics but also probability and statistics. Expecting knowledge in these subjects has implications in terms of school education."[24]

Yet part of the challenge for computational thinking is the lack of current evidence to support its teaching in the school context. As Wing notes, in contrast to maths and English, in coding and computational thinking "we really do not know when is the right age to teach what concept or what is the degree of reasoning capability a child needs to learn a given concept."[25] As such, countries have placed computational thinking in different curriculum locations; for example, Finland embeds the teaching of computational thinking across all subject areas, whereas the UK primarily teaches the skillset through coding.[26]

Within the Australian Curriculum, computational thinking is situated within the Technologies learning area, though it is also included in the general capability of ethical understanding. The ethical component of computational thinking includes a focus on developing students' capacity to understand and apply ethical and socially responsible principles to their experience, and to explore complex issues associated with the development and use of technologies.

Ethical reasoning

Wing and other researchers emphasise the need to teach ethical reasoning as part of computational thinking because of the profound breadth and impact of technology. This ethical dimension has a number of key considerations. Firstly, "if the human doesn't understand how to properly interpret the answer [a] machine produces, then something can go wrong."[27] Secondly, the interests of the software owner can become paramount, sometimes with inadequate attention to wider consequences, benefits or risks.

Toby Walsh, Professor of AI at the University of New South Wales, notes that it is critical to address the ethical

> “With society under a period of significant change, we will also need an informed population to navigate this future, and to demand appropriate checks and safeguards. A citizenship educated in ethics, society and civics is therefore essential. The education system needs to prepare us for this future of computational ethics.”
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> **Walsh, 2017**

questions arising from emerging AI-technologies as the technology develops. By enabling the automation of increasingly complex cognitive tasks, AI is providing the opportunity for people to rely on machines to make complex decisions. As AI has been put into such use, flaws and limitations with the data used in machine learning have been revealed, such as racial and gender bias, which can have significant implications when the technology is relied upon. Even more troubling, algorithms come to decisions in ways that are not completely clear to either their programmers or the general population.[28]

This has wide-ranging implications for how AI may impact on people and communities, from courts of law to highways and battlefields. While headlines about autonomous weapons and their significant geopolitical implications frequently dominate, the ethical questions raised are of significance for almost all applications of AI: is the technology built to behave ethically? Who is responsible when things go wrong? Has the potential for unintended consequences been thought through? Can we identify and correct what went wrong in the algorithmic calculations? Consequently, it is imperative that young people are skilled in considering the ethical implications of technologies that they use, design and will be otherwise impacted by.

Of course, strong ethical reasoning skills extend beyond technological design and impact, and many now suggest this needs to be more explicitly taught and firmly embedded in curriculum design across a range of disciplines. Ethical stewardship is not only becoming a more central concern in public policy and civic engagement but we also see predictions these skills will grow in the employment and business context, for example with predictions of “data compliance officers who help companies make ethical decisions about how data is used.”[29]

Metacognition - or Thinking about Thinking

Metacognition can be loosely defined as ‘thinking about thinking.’[30] The term may also be used as a pedagogical bridge connecting ideas such as ‘learning to learn,’ ‘thinking skills’ and ‘self-regulated learning.’[31]

Metacognition involves any cognitive behaviours directly linked with the individual’s control and monitoring of their own learning and thinking. These behaviours can include (but are not limited to): setting goals, making sure a problem is clearly understood before answering, monitoring memory recall and comprehension, reflection, generating and testing hypothesis, self-questioning, brainstorming ideas, and strategy selection. A key component of metacognition is that it involves the student evaluating and reflecting on their performance, and making changes to their learning behaviours, so that their learning process – including retention and output – is improved.[32]

There is still debate about the efficacy of this approach, but the research demonstrates that focusing on metacognition can help to improve students' thinking skills. A recent meta-analysis found that when metacognition is taught explicitly in schools, students are able to think more effectively across different curriculum areas.[33] This study suggests that metacognition may be more important than IQ in predicting success at school, and that explicit teaching of metacognition may provide students from lower socio-economic backgrounds with an equalising skill-set. Many high performing school systems, such as those in Hong Kong, Shanghai, Singapore and Finland already embed metacognition in their curricula and pedagogical practice.

What are some implications for us to consider?

Strong thinking skills are the foundation of learning both in students' schooling years and in their lives beyond. They are both integral to and closely interact with knowledge acquisition; knowledge cannot be gained nor thinking skills acquired without the other. Of growing criticality, thinking skills help discern and interpret information, which in our increasingly complex and changing world means robust thinking skills also create confidence and agency to control or shape one's circumstances. And thinking skills are uniquely human, in contrast to AI and machine learning.

This focus on thinking skills raises key questions for the education sector, including:

- If thinking skills are such a crucial foundation for learning, both within schooling and in the years beyond, are they sufficiently articulated and understood so as to support quality, explicit teaching of them, as well as assessment and evaluation of a student's 'thinking skill' acquisition?
- Do the current definitions of thinking skills in the Australian Curriculum appropriately capture the complexity and interrelatedness of different thinking skills? Do the discipline content areas adequately draw out the underpinning (and sometimes cross disciplinary) thinking skills?
- Do we have the right balance between learning discipline content and providing the opportunity for students to develop deeper thinking skills?
- Should more detailed learning progressions be developed to chart the expected development of thinking skills throughout schooling stages? Is there sufficient research yet to support what this might look like?
- Should proficiency levels be defined and assessed against these progressions? What does effective assessment of thinking skills look like?

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