THE FUTURE OF EDUCATION AND SKILLS

OECD Learning Compass for Mathematics

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OECD Learning Compass for Mathematics

In 2019 OECD's Education and Skills directorate launched the OECD Learning Compass 2030 (Learning Compass). This learning framework, developed by the Future of Education and Skills 2030 (E2030) project, offers a vision of future-ready education for all, grounded in the notion of student agency and driven towards the aspiration for greater well-being of individuals, communities, and the planet (OECD, 2023[1]).

This position paper considers how the components, identified in the Learning Compass align with new approaches to mathematical thinking (e.g., making more explicit the importance of helping students apply mathematics to resolve problems in the real-world and to develop mathematical reasoning). The goal is to open up more opportunities for student agency, which can lead to deeper learning and improved well-being. This alignment presents opportunities to extend and broaden mathematical knowledge, skills, attitudes and values in current curriculum content for 2030 and beyond.

This paper is one of several published or planned resources for countries and jurisdictions to consider the redesign of the mathematics curriculum within the context of the Learning Compass. In line with the multi-stakeholder, co-creation approach used to develop the Learning Compass, this paper has been co-developed among national experts, academics, statisticians, school mathematics experts, and professionals in mathematics-related fields. These co-creators have participated in a range of E2030 projects, studies and workshops on both curriculum design generally and mathematics curriculum specifically.

Over the last few years, the E2030 project has conducted two studies to map curriculum content in mathematics:

- the Mathematics Curriculum Document Analysis (MCDA) study, which demonstrates how current curriculum goals and teaching practice reflect changing emphases for mathematics and statistics education (e.g. learner-centred curriculum, competency-based curriculum, applications to real-world problems, cross-curricular competencies for deeper learning, math education for all, etc.) (OECD, 2020a[2]);
- the Curriculum Content Mapping (CCM) study, which analysed the extent to which competencies are explicitly referenced in curriculum content, including mathematics.

In addition, an international Mathematics Curriculum Analysis Report will soon be published, discussing the uniqueness of mathematics curriculum reform compared to other learning areas as well as key priority issues countries face in reforming curricula. These studies, together with the present paper, will be used as input to inform other publications on mathematics and to support policy makers, curriculum designers, mathematics educators, and teachers in their efforts to make the mathematics curriculum more future-oriented.

1. Education 2030: a shared vision

Underpinning the E2030 project is the premise that education needs to do more than prepare young people for the world of work. It also needs to equip them with the knowledge, skills, attitudes and values they need to become active, responsible and engaged citizens.

The Learning Compass components include:

- competencies (knowledge, skills, attitudes and values – not as competing concepts, but to be developed interdependently);

- the core foundations underpinning them (cognitive foundations, including literacy and numeracy, upon which digital and data literacy can be built);
- transformative competencies (creating new value, reconciling tensions and dilemmas, taking responsibility);
- and a cycle of anticipation, action, and reflection (A-A-R cycle) (OECD, 2023[1]).

By identifying these interdependent components, the OECD Learning Compass, suggests a multi-layered ecosystem in which the aim of learning – formal, non-formal and informal[1] – is to support future-focused participation in society. This paper considers these components through the lens of mathematics, to examine the extent to which they do, or can be, represented in mathematics curriculum (re)design.

Within the broader context of educational outcomes, mathematical thinking and reasoning are increasingly pertinent to the economic, political and social life in the 21st century and beyond. Mathematical thinking and reasoning are used in a growing range of occupations and are becoming increasingly significant in new opportunities for human advancement. For example, Artificial Intelligence (AI) requires complex algorithms, computer simulations and analyses of large amounts of data for economic, scientific and social planning, all require the application of mathematical knowledge and skills.

2. Need for new solutions in a rapidly changing world

Societies are changing rapidly, and often unpredictably. Students need to be future-ready, to engage effectively in the changes they will face in work and life.

2.1. The changing paradigm of work

Rapid changes in the world of work influence the kinds of mathematical knowledge, skills, attitudes and values needed for future jobs. The effect of the fourth industrial revolution is already being felt as economies shift away from manufacturing and many jobs are lost to machines (Schwab, 2016[3]) . In coming years, new technologies will increasingly perform work previously thought impossible, such as accountancy, knowledge creation, and office work (not only administrative tasks, but also reception tasks, customer service, payroll, data-entry, security, facilities management, and even content management for social media).

Increased automation poses a particular risk for workers in fields with a high level of routine tasks. For example, in the United States, the demand for such workers has been declining since the 1960s, in line with the increasing presence of computers and automation across all occupations (Autor and Price, 2013[4]). Only a few years ago, 47% of existing occupations were already at high risk of becoming automated in the near to medium term (Frey and Osborne, 2017[5]). Many of the occupations most resilient to automation will require workers to have mathematical and computational competencies coupled with several other future-oriented competencies to work within highly technological environments, to work effectively with technology, and to foster innovation.

The current manufacturing workforce needs skills and competencies that were not required by this sector in the past. They are tasked with, for example, maintaining complex websites, tracking inventory using sophisticated software, coding, and operating computerised assembly machines and robots. Essential competencies include a willingness and ability to learn,

[1] Formal education (provided by schools and training institutions), non-formal education (offered by community groups and organizations); informal education (experienced through interactions with friends, family and work colleagues (Coombs and Ahmed, 1974[63])

geometric and probabilistic reasoning, functional familiarity with statistical concepts and language, and familiarity with the logic and coding of computer programmes.

It is not just the 'trade-based' industries that are being revolutionised. The future of work will require that the mathematically and statistically literate design applications for mass use across industries and sectors as we see the rise of not only smart automation, but also of mobile technology, robotics, AI, smart sensors, augmented reality, big data analytics, location detection technologies, advanced human machine interfaces, cloud-based computing, etc.

The transportation sector is one example where the rise of drone technology opens up new potential for drone delivery of goods and purchases items (instead of delivery using drivers). This is already being tested out in small scale while waiting for specific legislation to regulate the sector and for its expansion to make this technology cost-effective (Harris, 2021[6]).

Construction is another case in point where 3D printing technology can support the construction of entire buildings by automated machines. 3D-printed houses, office buildings, and other small- and large- scale structures can be built in a matter of days holding promise for low-cost structures that can be helpful in emergency situations (e.g. shelters or housing in disaster areas), while respecting the environment (by using eco-sustainable materials) and being designed to resist earthquakes, for instance (Carolo and Haines, 2023[7]).

Increasingly, digital systems also allow users to enact complex tasks independently, from accounting and financial planning to law. Human and social services, too, will continue to be shaped by the incorporation of technological solutions (AI, robots, digital platforms, etc.)

2.2. The changing paradigm of life

Digitalization is already having an impact on all services in our lives, including how we communicate and interact with others, shop, earn our living, make and use money, obtain medical care, travel and plan leisure time, among others. The march of technological advancement has been driven by the promise (and delivery) of some very real opportunities to solve day-to-day problems, but also to tackle big problems, such as demographic and environmental challenges (including growing inequality).

Demographic challenges, such as projected population ageing and displacement, will continue to put pressure on the sustainability of public finances. To control costs and to optimise efficiency gains, digital systems are being used for the delivery of human and health services. End-users are increasingly required to be digitally literate to access and interact with such services' platforms. In the process, they are leaving important data behind that further strengthen the use of algorithms that rely on large data sets for various purposes, including for example, medical diagnoses in emergency centres and hospitals.

Individuals are thus becoming increasingly responsible for evaluating their own health to make decisions about treatment, medication and surgery. Such self-evaluation requires an ability to assess probabilities, dosages, side effects, and the likelihood of improved quality of life outcomes from treatments. Problem solving, decision making based on probabilities, understanding the limitations of real-world data and critical thinking are some of the essential competencies needed by all citizens to navigate this aspect of their lives.

Another important demographic challenge is the **risk of accelerated inequality** driven by rapid advancements in science and technologies. To address this, basic mathematical foundations for all children must be ensured from early years, especially as more automation and big data are used in daily life.

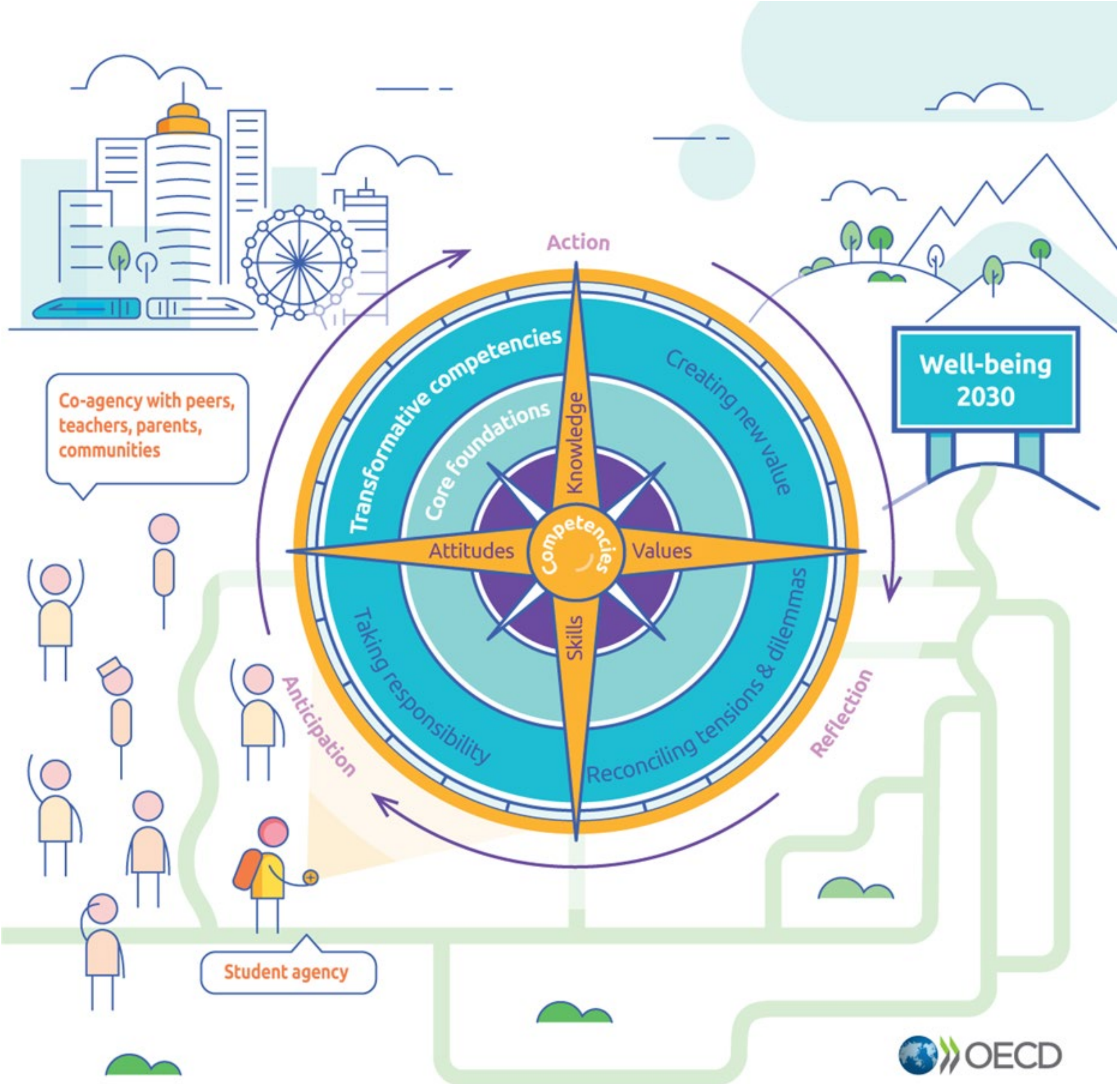
The **environmental impact of rapidly changing societies,** such as climate change and the depletion of natural resources - is not to be underestimated (OECD, 2018b[8]) The establishment of the United Nation's Sustainable Development Goal #13 on climate action in 2015 exemplified this). Here again, mathematics literacy is needed in the search for sustainable solutions.

Mathematical representations are at the basis of understanding and illustrating problems, such as population growth, waste, resource scarcity, air and water pollution, and electrical energy demand (Schwartz, 2010[9]). Calculus models are applied to problems such as heating and cooling substances, designing load-bearing structures, and accurately predicting the orbital paths of satellites. Additionally, mathematical models are used to predict the outcomes of societal and environmental phenomena without the real-world consequences. For example, stochastic modelling was used to predict the number of people infected with COVID-19 during the recent pandemic and to simulate the effect of various policies on COVID-19 transmission prior to them going into effect.

3. Need for broader educational goals: Individual and collective well-being

The need for well-being to drive economic, social and educational equality is reflected in its centrality within the OECD Learning Compass. Education develops the knowledge, skills, attitudes and values that enable students to contribute to and benefit from society in ways that improve quality of life for themselves, for others and for the environment. It also needs to equip students with competencies to allow them to diagnose and solve problems, respond actively, creatively and responsibly to others and to enable and enhance social engagement.

Figure 1. OECD E2030 Learning Compass



OECD (2023[1]), "OECD Future of Education and Skills 2030: Learning Compass 2030," https://issuu.com/oecd.publishing/docs/e2030-learning_compass_2030-concept_notes?fr=xKAE9_zU1NQ (accessed 25 Sep 2023)

3.1. Student agency: Navigating through a complex and uncertain world

Student agency, and the related competency of co-agency, underpin the OECD Learning Compass. Agency acknowledges that students have the ability and the desire to positively influence their own lives and the world around them. It is defined as the capacity to set goals, reflect and act responsibly to effect change. It involves acting rather than being acted upon; shaping rather than being shaped; and making responsible decisions and choices rather than necessarily accepting those determined by others (OECD, 2019d[10]).

Agency involves planning, taking action and initiative to achieve goals, reflecting on feedback and advice, and taking responsibility for actions. This competency is acquired through the development of knowledge, skills, attitudes and values related to goal setting, monitoring progress, coping with setbacks, reflecting and evaluating.

Concepts such as identity, self-worth, sense of belonging, motivation, hope, self-efficacy, growth mindset, and a sense of purpose (OECD, 2019d[10]) are related to student agency. The OECD's Programme for International Student Assessment (PISA) shows mathematics performance is strongly aligned with mathematics self-efficacy (OECD, 2013[11]).

Mathematical self-efficacy refers to a learner's beliefs about their own ability to perform various mathematics-related tasks, and research shows that these beliefs can impact the learners' mathematics performance. Figure 2 shows that countries with higher mean performance in mathematics in PISA are those where students are more likely to report feeling confident about being able to solve a range of pure and applied mathematics problems.

Figure 2. Country-level association between mathematics performance and mathematics self-efficacy

Source: (OECD, 2013[12])

Other constructs related to student agency in mathematics included in the PISA 2022 assessment framework are self-direction, initiative and persistence.

Co-agency in mathematics learning is developed when students as well as teachers learn through collaboration with their peers, such as when finding solutions through creative, co-operative, problem-solving exercises (Nicol, 2004[13]; Chaaban, 2021[14]).

Future-ready students act positively on their environments, and embrace change by considering others' views, intentions and feelings and anticipating short- and long-term consequences. Students can develop knowledge, skills, attitudes and values as part of essential learning at school. Schools can also work as a bridge to help students connect their learning to the real world, going well beyond school walls.

3.2. Core foundations

The OECD Learning Compass defines core foundations as the core skills, knowledge, attitudes and values that are prerequisites for further learning across the entire curriculum. The core foundations provide a basis for developing student agency and transformative competencies. They are also the building blocks upon which context-specific competencies, such as financial literacy, global competency or media literacy, can be developed.

The OECD Learning Compass highlights three classifications of foundations as particularly important

- cognitive foundations, which include literacy and numeracy, upon which digital literacy and data literacy can be built;
- health foundations, including physical and mental health, and well-being;
- social and emotional foundations, including moral and ethics.

Of these core foundations areas, numeracy, data literacy and digital literacy are found to be most relevant for developing the broader competence of mathematics literacy. Given the expansion of digitalization and “big data” into all areas of life, all students need strong data and digital literacy and the confidence to apply them across diverse situations.

3.2.1. Literacy

Literacy can be understood to be the “ability to comprehend, interpret, use and create textual and visual information in various formats, contexts and for diverse purposes (making meaning based on encoding and decoding signs/sign systems)”, thus underpinning human communication, through oral, visual and written language (OECD, 2019b[15]). The OECD Learning Compass 2030 emphasizes the importance of literacy as a foundation skill for learning; such foundation is essential to support learning in all subjects, including mathematics. Recent research has shown that literacy is a key factor in successful mathematics learning (Žakelj et al., 2019[16]; Fuchs et al., 2001[17]).

For a successful learner of mathematics a large enough vocabulary and the ability to read and understand word problems are essential, in addition to the knowledge and understanding of numbers, symbols, and relations among them (Žakelj et al., 2019[16]). Furthermore, reading literacy can support learners not only to understand, but also to analyze, interpret, and communicate mathematical ideas. It can help learners develop the type of higher-order cognitive skills (e.g. reasoning skills, creativity, critical thinking, decision-making, idea generation, concept acquisition, problem-solving skills, etc.) that can support the development of mathematical thinking and reasoning (Bernabini, Bonifacci and de Jong, 2021[18]; Rutherford-Becker and Vanderwood, 2009[19]);

3.2.2. Numeracy

Numeracy is defined as “the ability to access, use, interpret and communicate mathematical information and ideas to engage in and manage mathematical demands of a range of situations” (PIAAC Numeracy Expert Group, 2009[20]). It can also be understood as the ability to use mathematical tools, reasoning and modelling in everyday life, including in digital environments. This includes applying the knowledge and skills acquired from mathematics to subject-specific content in other subject areas, where appropriate.

This is well in line with the definition of mathematics literacy in the PISA Mathematics Framework, 2021:

Mathematical literacy is an individual's capacity to reason mathematically and to formulate, employ, and interpret mathematics to solve problems in a variety of real-world contexts. It includes concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to know the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective 21st century citizens (OECD, 2018a[21]).

The definition in the PISA framework explicitly positions mathematics and statistics in the service of problem solving within real-world contexts. It reflects the importance attached to mathematical and statistical modelling which are playing an increasing role in reasoning and human decision-making.

Understanding the neural differences in how students process mathematical information can help tailor instruction to individual learning styles. For example, for students who struggle with algebra but excel in geometry, mathematics educators can contribute to research design in neuroscience while neuroscience researchers can validate theories of mathematics education (Leikin, 2018[22]). This integration will continue to support curriculum designers and teachers in the future, especially when considering how to design curriculum and effective instruction strategies that are aligned with findings from brain science about mathematical learning, e.g. how to align content, cognitive readiness, learning sequences, etc.

3.2.3. Data literacy, including information use

The definition of literacy will continue to evolve to also include digital and data literacy, especially as digitalization increasingly populates our daily lives with a wide range of information as well as Big Data shared in all formats, e.g. written text, graphs, charts, signs, etc. (OECD, 2019b[15]).

Data literacy is defined as "the ability to derive meaningful information from data, the ability to read, work with, analyse, and argue with data" (OECD, 2019b[15]). Data literacy includes thinking critically about information presented in statistical or visual formats (e.g. reading charts), analyzing the data, drawing appropriate conclusions from data, and determining the accuracy of claims made based on them (Carlson et al., 2011[23]).

Data can include both quantitative and qualitative information. Information use includes the use of information accurately and creatively for the problem at hand, and the management of the flow of information from a wide variety of sources (P21., 2018[24]).

3.2.4. Digital literacy

Digital literacy is defined as the interest, attitude, and ability to use information and communication technologies effectively, appropriately and safely in education settings, and in professional and daily life. Digitally literate students can access, interpret, manage, integrate, and evaluate information and concepts, construct new knowledge, and communicate this, using digital devices in an ethical and responsible way (Lennon et al., 2003[25]). They are also able to adapt to changing technologies and use those technologies to achieve a purpose. Digitally literate students can act as an active citizens not only in physical but also digital space, often referred to as 'Digital Citizenship', for which mathematical thinking and reasoning will continue to be relevant.

The rise of generative A.I. (e.g., the rapid popularity of ChatGPT) poses important risks and opportunities to both teachers and students alike. Being digitally literate will require learners' increased awareness of related risks (e.g., data privacy/security risks, plagiarism, information bias, job losses) and opportunities (e.g., increased productivity, access to relevant references, ideas generation, creation of new jobs, etc.). Digitally literate learners will increasingly need to be able to make judgements about such risks and opportunities – real or perceived - especially as generative AI blurs the boundaries between individual and collective creation, human and machine creation, and between knowledge creators and knowledge consumers. The rise of digitalisation will continue to push the boundaries of what it means to be literate and numerate now and in the future (OECD, 2019b[15]).

3.2.5. Health, and socio-emotional foundations

For students to build the cognitive foundation (i.e. literacy, numeracy, digital literacy and data literacy) through sustained learning, they first need to be in good overall health – both physical and mental. This is a pre-requisite not only for learning but for their own well-being. "Health", as a state of 'being healthy' rather than 'having health literacy', is therefore included as a core foundation in the OECD Learning Compass 2030 (OECD, 2019b[15]).

For instance, the benefits of physical activity on children's health and wellbeing are well established and have been shown to have a positive impact on academic performance, including in mathematics (Sneck et al., 2019[26]). Children and young people who are physically active, have a nutritious diet and adequate sleep are also more likely to attend school, and do well at school" (Burns, 2018[27]; Gruber et al., 2010[28]).

Mental health is another important condition for learning. Low self-esteem, social stereotypes, negative experiences with mathematics, inadequate messages about mathematics ability or talent as well as unrealistic expectations about mathematics performance, can all contribute to "math anxiety" in learners, especially among those from socio-economically disadvantaged backgrounds (Richardson and Richard M., 1972[29]). Math anxiety in turn may affect students' sense of self-efficacy for learning mathematics, lead to lower academic performance, avoidance of mathematics-related activities, negative attitudes towards mathematics, and lower self-esteem, thus negatively affecting learners' socio-emotional development (Richardson and Richard M., 1972[29]). Learners' activation of negative stereotypes about their own social group (e.g. gender, racial, ethnic, cultural group) in relation to mathematics ability can also trigger cognitive overload, stress and anxiety in students, undermining their performance (Steele and Aronson, 1995[30]; Spencer, Steele and Quinn, 1999[31]; Stoet and Geary, 2012[32]).

Math-related anxiety and stress related to "fear of failure' is experienced by a large proportion of students in every country. Recent PISA findings reveal that 15-year-old girls expressing greater fear of failure perform better in mathematics than their counterparts (OECD, 2019[33]). While some literature suggests that moderate levels of fear of failure can lead students to make greater efforts in learning, there is also evidence suggesting its potential threat to one's social and emotional well-being (OECD, 2019[33]). In PISA, on average across OECD countries, students with greater fear of failure showed lower levels of life satisfaction, an effect that is more pronounced among girls (OECD, 2019[33]).

'Health' – being physically and mentally healthy – is an essential requirement and condition for students' quality learning and well-being. Furthermore, they reinforce each other, i.e. better learning can support greater well-being and vice versa in the long term.

3.3. Transformative competencies to transform our society and shape our future

The OECD Learning Compass 2030 defines transformative competencies as the types of knowledge, skills, attitudes and values students need to transform society and shape the future for better lives. These specific competencies are transformative both because they enable students to develop and reflect on their own perspective, and because they are necessary for learning how to shape and contribute to a changing world (OECD, 2019c[34]).

These have been identified as:

- creating new value;
- reconciling tensions and dilemmas;

- taking responsibility.

Creating new value refers to a person's ability to innovate by making informed choices and taking responsible actions (OECD, 2019e[35]). It involves critical thinking and creativity in finding different approaches to solving problems, and collaboration with others to find solutions to complex problems.

Reconciling tensions and dilemmas is the skill of balancing seemingly contradictory or incompatible demands (OECD, 2023[1]). As this can involve making complex and sometimes difficult decisions, students need to develop attitudes and values such as resilience, and skills such as creativity and problem solving to devise new solutions.

Taking responsibility means that a person can reflect upon and evaluate his or her actions in light of his or her experience, personal and societal goals, what he or she has been taught, and in light of ethical considerations (Canto-Sperber and Dupuy, 2001[36]). This competency can include skills such as critical thinking as one reflects on one's actions and the actions of others. Having a sense of self-direction is of particular importance.

These transformative competencies can be used across a wide range of situations and are uniquely human. All three are competencies that help learners navigate personal and social situations and experiences. In that sense, they are highly transferable and can be used throughout life.

Each of these transformative competencies can be developed as part of mathematics literacy, and incorporated into existing curricula and pedagogy, as part of disciplinary and cross-curricular learning. For example, these transformative competencies can be mobilised to help students work on unfamiliar, challenging, higher order thinking problems rather than routine, familiar ones, and to persist in face of failure. Certainly, critical thinking, reflecting on and adjusting approaches to solving complex problems are integral to the discipline of mathematics.

3.4. Compound competencies

Compound competencies are combinations of the knowledge, skills, values and attitudes associated with emerging demands from society, such as financial literacy or media literacy. They can be developed on top of the core foundations, which act as building blocks, and they differ from the core foundations in that they are domain- or context- specific. The OECD Learning Compass suggests compound competencies such as global competency, media literacy, entrepreneurship, computational thinking, literacy for sustainable development, and financial literacy.

- Computational thinking/ programming/ coding

Computational thinking involves formulating problems and developing solutions that can be carried out by computer-based technologies. Programming and coding involve the development of knowledge, understanding and skills regarding the language, patterns, processes and systems needed to direct devices such as computers and robots.

- Literacy for sustainable development/ environmental literacy

Literacy for sustainable development refers to the knowledge, skills, attitudes and values needed to promote sustainable development. To be literate in sustainable development requires understanding how social, economic and environmental systems interact and support life, recognizing and appreciating different perspectives that influence sustainable development and participating in activities that support more sustainable ways of living.

Mathematics literacy is clearly relevant in considering, analysing, predicting and posing solutions to enhance sustainable development. Relevant skills include computation, problem solving, visually representing data, and mathematical modelling.

- Financial literacy

Financial literacy is the ability to apply financial knowledge and skills to real-life issues and decisions. It involves knowing and understanding financial concepts and risks, and the skills, motivation and confidence to apply such knowledge and understanding to make effective decisions across a range of financial contexts. Financial decisions are part of everyone's lives from a young age, whether it be saving and spending pocket money, entering the world of work, managing one's own budget, purchasing goods, saving for future expenses, understanding credit and loan payments, or retirement planning. Financial literacy helps individuals to navigate these decisions and strengthens their financial well-being as well as that of society as a whole, as it promotes inclusive growth and more resilient financial systems and economies.

3.5. Knowledge

The Learning Compass recognises that knowledge includes theoretical concepts and ideas as well as practical understanding based on experiential learning. It identifies four types of knowledge: disciplinary, interdisciplinary, epistemic and procedural.

Disciplinary knowledge, or subject-specific knowledge, is a foundation for understanding, and a structure through which students can develop other types of knowledge. The opportunity to acquire disciplinary knowledge is also fundamental to equality. Disciplinary knowledge continues to be a core element of curriculum design internationally and a common structural focus for teaching and learning in schools.

Interdisciplinary knowledge involves transferring key concepts and ideas and identifying connectedness across disciplines of learning. It may be structured through, for example, thematic or project-based learning opportunities. In curriculum terms, this may be through integrating or combining related aspects of disciplinary subjects or creating a new subject.

Epistemic knowledge is knowing how to think and act like a practitioner. It shows the relevance and purpose of students' learning and helps deepen their understanding of a discipline or disciplines.

Procedural knowledge involves knowing how a task is performed, and how to work and learn through structured processes, such as solving complex problems.

3.5.1. Disciplinary knowledge

Disciplinary knowledge and content remain foundational in mathematics learning as students develop 21st century skills, attitudes and values that extend, relate to and build upon them. A mathematics framework needs to retain relevant content while being able to expand itself to be inclusive of emerging topics.

For example, a redesigned curriculum would put greater emphasis on data analysis and computational thinking, recognizing the importance of these fields on information and programming technology. At the same time, curriculum reform needs to consider the risk of "curriculum overload". The mere addition of new content to curriculum is likely to overburden teachers and students in the absence of some strategic thinking about its importance and how it can be best integrated into existing curriculum. Curriculum designers are therefore encouraged to follow the design principles of focus, rigour and coherence to make decisions about how new knowledge can be incorporated into content without lowering standards (a curriculum that is a mile-wide and an inch deep) and while ensuring optimal learning progressions for students (OECD, 2020[37]).

The following content areas are fundamental to mathematics in the years between primary/elementary and lower secondary/college.

- quantity (whole number, fractions and decimals, number sense and estimation, number systems, other number concepts);
- space and shape (position, visualisation and shape, symmetry, congruence and similarity);
- change and relationships (algebra foundations, beginning algebra, algebra, change);
- uncertainty and data (descriptive statistics, probability distributions, statistical inference);
- relationship between knowledge of basics and mathematical concepts and capacity to use digital tools (knowing why the calculator function chosen is the right one, trusting the answers the calculator gives, and checking a given answer for reasonableness in relation to the problem);
- mathematical modelling (i.e., representing relevant aspects of a situation in mathematical terms);
- assessing plausibility (i.e., acknowledging when conclusions, methods or assumptions are not plausible/reasonable, and acting on it).

3.5.2. Interdisciplinary knowledge

Interdisciplinary knowledge allows the creative application of mathematics across fields of knowledge. This might involve:

- connecting mathematics with other in-demand competencies (e.g., computational thinking, environmental literacy, financial literacy, etc.);
- grouping subject or learning area knowledge linked to mathematics in meaningful ways, e.g., science, technology, engineering and mathematics (STEM); this approach reflects the ongoing changes in the world of work;
- more recent initiatives such as science, technology, engineering, arts and mathematics (STEAM), which encourage educators to incorporate the arts into interdisciplinary approaches to learning, broadening the range of skills students develop prior to entering the workforce.

The demand for workers in fields that integrate STEM is increasing, with the potential to widen economic opportunities. High status STEM professions requiring big data processes and automation, such as diagnosis processes in medicine or virtual reality-supported design procedures in engineering, are becoming more prevalent (Tytler, 2020[38]). If given appropriate attention in primary and secondary education, STEM-related skills can contribute to bridging some persistent equity gaps in societies. (Fine et al., 2019[39]). The global focus on STEM education reflects countries' desire to build strong economies and enhance societal well-being. (Tytler, 2020[38]).

Ethnomathematics, which brings together mathematics and cultural studies, promotes mathematical concepts and systems from different cultural perspectives. It can promote cross-cultural harmony as students examine how mathematics is embedded into their own cultural traditions and those of other cultures and how it lives well beyond a school discipline (Owens, 2017[40]). As students learn the different ways cultural groups around the world have developed and used mathematics, they will see mathematics as a human endeavor, and learn about the rich cultural history of mathematics. Examples of ethnomathematics include the study of patterns, rhythms, chord progressions, and melodies found in music (Presmeg, 1998[41]) or the analysis of ratios, patterns and symmetry in Japanese origami (Brandt and Chernoff, 2015[42]).

Another approach is to consider mathematics as a human endeavor over time, by studying the history of mathematics and its roles in societies. If students learn the history of mathematical creativity, they will be able to understand its origins and appreciate that there is opportunity for innovation in the rules and methods of mathematics. Without this understanding, students are only users who learn and apply mathematics as a static system of rules, without knowing the big debates mathematicians have had over rules, axioms and procedures, and how new mathematics arose because of such disagreements (Martínez, 2012[43]).

3.5.3. Epistemic knowledge

Epistemic knowledge is about how mathematicians and statisticians learn and advance mathematical knowledge. It is also about the fundamental nature of the structure of mathematics and statistics, as related but different disciplines.

Thinking like a mathematician or statistician allows students to extend their disciplinary knowledge and develop inquiry skills or thinking processes, which further advance their proficiency. Examples of processes[2] involved in the development of epistemic knowledge include:

- problem solving and investigating;
- representing and communicating;
- making connections;
- visualising;
- modelling;
- identifying patterns in data;
- thinking logically (mathematics) and stochastically (statistics) when explaining and justifying;
- considering alternatives and weighting conflicting evidence;
- carrying out procedures with fluency and flexibility;
- using technology and other tools.

Some mathematical concepts are frequently described as "big ideas" or "themes" (OECD, 2020[37]). Commonly, these ideas include knowledge about:

- number systems (whole numbers, integers, rational numbers);
- equivalence/ equality and comparison;
- operations and their relationships;
- patterns and relationships;
- invariance and variation;

[2] When designing curriculum, countries may highlight slightly different (but related) processes involved in the development of epistemic knowledge. For example, the Mathematics Australian Curriculum identifies the processes of "manipulating mathematical objects, generalising, thinking and reasoning, problem-solving and inquiry" as key to understanding mathematical approaches (ACARA, 2021[66]) whereas the Singapore Mathematics Curriculum Framework highlights: "reasoning, communication and connections, applications and modelling, thinking skills and heuristics" (Ministry of Education, Singapore, 2012[67]). This is in line with an effort in many countries to emphasise the need for conceptual understanding of mathematics (rather than disconnected factual knowledge) when designing curricula (OECD, 2020[37]).

- symbolic and diagrammatic systems;
- measurement of attributes and working with measures;
- variables and co-variation, including relations and functions;
- distributions and variability;
- probability as measurement of likelihood;
- definition of shapes and solids by properties and classification;
- transformations and navigation.

Big ideas provide a taxonomy by which smaller ideas can be organised and connected. More importantly, they provide an opportunity for students to learn the recurrent themes of the disciplines of mathematics and statistics (OECD, 2020[37]).

3.5.4. Procedural knowledge

The Learning Compass lists "system thinking" and "design thinking" as transferable or transversal procedural knowledges. In mathematics, system thinking includes research and inquiry, as well as algorithm, as relevant and ubiquitous procedural knowledge.

- System thinking is the ability to think about a system as a whole, rather than only considering the parts individually. It conceives the world as a complex system and supports the understanding of its individual parts and their interconnectedness (Sterman, 2000[44]).
- Research is the systematic investigation into and study of materials and sources to establish facts and reach new conclusions. Inquiry in mathematics, as in other disciplines, requires students to engage in active learning by generating their own questions, seeking out answers, and exploring complex problems (Holland, B., 2017[45]).
- An algorithm in mathematics is a procedure, a description of a set of steps that can be used to solve a mathematical computation. Today, algorithms are used in many branches of science, as well as in everyday life. They are all about finding efficient ways to do the mathematics. In mathematics curriculum, traditional strategies involve memorising ancient algorithms, but in recent years teachers have started to teach the idea of algorithms by showing there are multiple ways to resolve complex problems by breaking them into a set of procedural steps (Russell, 2018[46]). Developing students' algorithmic thinking means supporting them to use their creativity and find new ways of resolving problems in different (and possibly more efficient) ways.

3.6. Skills

Skills are the ability to carry out processes and be able to use one's knowledge in a responsible way to achieve a goal (OECD, 2023[1]). Skills are part of a holistic concept of competency, involving using knowledge, skills, attitudes and values to meet complex demands. The OECD Learning Compass distinguishes three different types of skills:

- cognitive and metacognitive;
- social and emotional;
- physical and practical.

This paper pays particular attention to the skills that automation cannot easily replace, often called "21st century" skills. These skills intersect with and enable the mathematical processes and disciplinary capabilities listed earlier whenever students act as mathematicians and statisticians.

3.6.1. Problem solving

Problem solving refers to an individual's capacity to engage in cognitive processing to understand and resolve situations where a solution is not immediately obvious (OECD, 2016[47]). Problem solving is multi-faceted and multi-dimensional and can include interpersonal, intra-personal and social problem solving as well as interdisciplinary problem solving. Problems in daily life, including in professional contexts, often require some level of understanding of mathematics, mathematical reasoning or the use of mathematical tools, before they can be fully understood and addressed.

3.6.2. Critical thinking

Critical thinking, defined as questioning and evaluating ideas and solutions (Haber, 2020[48]; Sellars et al., 2018[49]; OECD, 2016[47]), is a higher-order cognitive skill and includes inductive and deductive reasoning, analyzing, making inferences and evaluating (Facione, Giancarlo and Facione, 1995[50]; Liu, Frankel and Roohr, 2014[51]).The cognitive capacities underlying critical thinking are developed in the context of general or specific problem solving in a particular area of knowledge or expertise (Haber, 2020[48]; Sellars et al., 2018[49]). Mathematics requires critical thinking – when individuals draw on knowledge and use logic and reasoning - or stochastic thinking[3] to make sense of a problem. For example, a financial problem might involve weighing up whether buying something in bulk may be beneficial, wasteful or unaffordable in the short and long terms. On the other hand, critical thinking is also enhanced by mathematics, allowing one to, for example, notice anomalies in patterns or alarming trends in data, and question unsound use of statistical metrics.

3.6.3. Creativity

Creativity, defined as the ability to approach problems or situations from a fresh perspective resulting in seemingly unorthodox solutions, is the process through which novel ideas, approaches or information are developed (Mumford, Medeiros and Partlow, 2012[52]).

Creativity has been central to the evolution of mathematics and statistics, as innovations in rules and methods have brought it from its ancient origins to present-day practice. Throughout history mathematicians have created new theorems and even branches of mathematics, sometimes to solve real-world problems and sometimes creating new fields of knowledge. While creativity is an essential skill for both mathematical problem solving and advancing the field of mathematics, mathematics can also contribute to creativity. From complex mathematical problems to complex interdisciplinary problems, creativity is needed to find solutions.

While the question of how this competency is best developed in individuals remains central in various fields, neuroscience research shows that the brain regions activated in the performance of creative tasks are the same ones recruited for everyday tasks suggesting that creativity is not a specific brain function, but that it relates and relies on the concurrent application of every cognitive tasks (e.g. problem-solving, transfer of knowledge, evaluation, etc.). Unfamiliar/novel situations or a problem for which an immediate answer is unknown is the type of trigger that can support the emergence of divergent and convergent thinking through which creativity is manifest, both in general but also in the domain of mathematics (Cropley, Westwell and Gabriel, 2016[53]).

[3] Stochastic thinking looks at the system underlying its parts (instead of looking at isolated problems) and seeks to solve problems aiming at the stability of the whole system (Eichler et al., 2009[64]).

For example, a school wants to double the surface area of its outdoor play space without damaging the trees along the perimeter. One approach to resolve this may be through the creative mathematical exploration of space and shape. Another creative approach to solve the problem may involve looking first at the reasons behind the need to expand the school outdoor play area, in which case one can consider asking other questions, such as "which preferred activities do users want to engage in?" as a way to expand the range of possibilities. Problem solving, critical thinking and creativity could all be applied to find a solution.

3.6.4. Communication

Communication is a skill of mathematics literacy. Reading, decoding and interpreting statements, questions, tasks or objects enable students to form a mental model of the situation, an important step in understanding, clarifying and formulating a problem and its solution. Solution processes involve intra-personal, as well as inter-personal, communication, supported by cultural tools such as words, written symbols, and diagrams. Once a solution has been found, the problem solver may need to present the solution, and perhaps an explanation or justification, to others (OECD, 2013[11]).

At the heart of communication lies conveying ideas and concepts in efficient ways. As data and numbers becomes increasingly important in managing human society, it also becomes increasingly important to efficiently communicate the meaning of data and the background of the data. Applying and presenting statistics and explaining quantitative processing of data are parts of mathematical communication.

3.6.5. Self-direction, learning to learn (aligned to agency)

Learning to learn can be defined as the state of "being aware of and taking control of one's own learning" (Biggs, 1985[54]). It refers to an awareness and understanding of the phenomenon of learning itself as opposed to subject knowledge and enables students to take control of their own learning. For students to know how to apply their learnings to practice, the curriculum needs to help them recognise the relevance and purpose of what they are learning. For example, engineers learn to solve engineering problems. An innovative curriculum would help them develop their own thinking about the types of problems they wish to resolve, which requires self-directed learning.

3.7. Attitudes and values

The Learning Compass positions attitudes and values as competencies. This positioning aligns with productive disposition and agency as processes/disciplinary capabilities, as discussed previously. Attitudes and values are defined as:

the principles and beliefs that influence one's choices, judgements, behaviours and actions on the path towards individual, societal and environmental well-being (OECD, 2019a[55]).

The Learning Compass acknowledges that identifying and classifying values is dependent on local context. For the purposes of the E2030 project these are categorised as:

- Personal values: associated with who one is as a person, and how one wishes to define and lead a meaningful life and meet one's goals.
- Social values: related to the principles and beliefs that influence the quality of interpersonal relationships and make community and society work effectively.
- Societal values: the shared principles and guidelines that frame each culture and society.
- Human values: values which transcend nations and cultures, are in service of the well-being of humanity, and are often articulated in internationally agreed conventions, such

as the Universal Declaration of Human Rights and the United Nations Sustainable Development Goals (SDGs).

In mathematics, particular emphasis is placed on the importance of persistence and resilience, defined as the capacity of an individual to maintain prolonged effort and commitment in the face of adversity. The OECD framework quotes the reflections of one student involved in a 2017 seminar as exemplary of the need for students to be resilient.

He added that studying mathematics needed patience, commitment, willingness to trial and error, knowing that some concepts would be more difficult to grasp and having the resilience to understand these difficult concepts. And, he suggested that teachers be honest about the discipline not only making it sound easy and fun at all times. (Schmidt et al., 2022[56])

The capacity to combine knowledge with skills, attitudes and values and apply them in unfamiliar circumstances is uniquely human. For example, Luckin and Issroff (2018[57]) identify what people should know and be able to do with AI, and refer to a combination of knowledge (basic AI concepts, digital literacy, data literacy, online safety protocols), skills (basic AI programming, AI systems building), attitudes and values (ethics of AI). Ethical understanding of the opportunities and limitations of AI is crucial to its future use, both in how systems are developed and in how people can make good and effective use of them.

4. Anticipation-Action-Reflection (AAR) cycle

The Anticipation-Action-Reflection (AAR) cycle is an iterative learning process whereby learners continuously improve their thinking and act intentionally and responsibly, moving over time towards long-term goals that contribute to collective well-being. Through planning, experience and reflection, learners deepen their understanding and widen their perspective.

Each stage of the AAR cycle is important in developing mathematics literacy. The three stages inform, complement and strengthen each other. For example, if action is taken without anticipation, the learner is not considering the possible consequences of the action. Furthermore, while skills such critical thinking and decision making are developed through reflection, they are also skills that are required for effective anticipation. Neuroscience research combining neuroimaging and behavioral data of mid-school Korean students has shown the importance of the inhibitory control (cycle of anticipation, action, reflection) in learning sciences and mathematics highlighting the value for learners to “pause” before responding .

4.1.1. Anticipation

Anticipation is the ability to understand one’s own intentions, actions and feelings and those of others, and anticipate short- and long-term consequences. It is also the ability to widen one’s perspectives, as well as preparedness to create and influence the future. In mathematics, a process such as predictive modeling requires anticipation.

4.1.2. Action

Action as a competency involves the ability to act for a defined purpose. Actions may be investigative, such as solving a mathematical problem, oriented towards taking responsibility, such as personal financial planning, focused on making changes, such as experimenting with an update to a computer programme.

4.1.3. Reflection

Reflection is the ability to take a critical stance before acting, such as, by stepping back from the assumed, known, apparent and accepted, examining situations, from different perspectives, and considering the long-term and indirect effects of one’s actions. It involves thinking back on previous learnings and experiences and learning from them (OECD, 2016[47]). This can be helpful in a mathematics context because mathematical problem solving involving reasoning, and argument requires reflection. Tasks in which students must use a mathematical tool also require reflection to understand and evaluate the merits and limitations of the tool.

5. Design principles for moving toward an eco-systemic change

This paper calls for epistemic change from policy makers, school leaders, teachers and students. A mathematics curriculum that can meet the changing demands of society needs to focus on developing students as "thinkers" of mathematics, not just "doers". In asking students to think differently, teachers and those who support them, will also need to make an epistemic change to their practice (Leonard and Fitzgerald, 2018[58]; Markauskaite and Goodyear, 2017[59]).

The E2030 Learning Compass presents a complex framework of developmental, learnable competencies that are intricately related. The AAR cycle acts a model to consider how to mobilise knowledge, skills, values and attitudes through a manageable process of design for change, underpinned by a set of principles within a discipline, across disciplines, beyond school and for processes (OECD, 2020a[2]).

Curriculum revision and development processes operate variably across national and jurisdictional contexts, so the design principles are intended as a guide for curriculum redesign that can be contextualized locally and, in the case of this paper, mathematics specifically.

5.1. Design principles relevant to mathematics

Design principles for **content within a discipline** are:

1. **Focus**: introducing a small number of topics per grade, to ensure depth and relevance; in mathematics this may be ensuring that a limited number of concepts are introduced and allowing time for their real-world relevance to be explored. The challenge in mathematics curriculum design is to ensure coverage of essential content, without overload.

2. **Rigour**: content should include topics that are challenging and allow deep thinking and reflection. Included content should be carefully selected and evidence-based, to ensure it can develop students' capacity to use knowledge and apply skills in new and different contexts. A particular challenge in mathematics is the strong tradition of including certain content which may no longer be needed or relevant in today's world.

3. **Coherence**: content needs to be meaningfully sequenced to allow for clear, developmental progression that is age and grade appropriate. Coherence does not mean rigid, linear progression, but rather a sequenced progression that caters for staged development. Mathematics, with its hierarchical and sequenced structure of topics and concepts, lends itself to particular interrogation. An important question is how broadening knowledge and skills to allow for mathematical thinking and reasoning in real-world contexts can be incorporated without causing overload; another question is how developments in the learning sciences or new findings from brain science can better inform content selection and sequencing in mathematics curriculum development.

Design principles for **content across disciplines** are:

1. **Transferability**: students need to be able to understand concepts or big ideas that underpin a subject and that apply across subjects (OECD, 2020[37]). A transferable curriculum recognises how students can develop and apply knowledge, skills, attitudes and values across disciplines and contexts. The applicability of mathematics content to other disciplines is widely recognised, in areas such as STEM, STEAM and in other areas of collaboration, such as ethnomathematics (OECD, 2020[37]).

2. **Interdisciplinarity**: a curriculum that favours interdisciplinarity and interrelatedness should provide students with opportunities to explore topics from multiple disciplinary traditions. The hierarchical structure of mathematics provides a platform to consider how students can develop an understanding of the ecosystem within which broader learning of related topics and concepts takes place.

3. **Choice**: a curriculum designed to maximise choice should offer students a range of topics, projects, options and opportunities for learning. In mathematics, consideration might be given to resources, or innovative approaches to planning, teaching and assessing, with a particular focus on the relevance of learning experiences.

Design principles **beyond school** are:

1. **Authenticity**: students need to be able to link their learning to contemporary contexts and real-world scenarios, and to have a sense of purpose in their learning. In mathematics, this requires mastery of discipline-based knowledge, as well as interdisciplinary and collaborative experiences outside school.

2. **Flexibility**: curriculum redesign needs to be adaptable and dynamic, so that schools and teachers can update and align teaching and learning programmes to reflect evolving demands from society and from students. Mathematics, as has been shown in this paper, is a discipline that links explicitly to the changing paradigms of work and life.

3. **Alignment**: curriculum should be aligned with teaching pedagogy and assessment practices, across levels of education. Coherent alignment of practices maximises the opportunity for curriculum alignment. In mathematics, there are opportunities to balance preparing students for tests and examinations with facilitating opportunities for creative mathematical thinking and reasoning.

Design principles for **processes** are:

1. **Engagement**: teachers, students and other relevant stakeholders should be involved early in the development of the curriculum, to encourage them to feel ownership and, therefore, for effective implementation. Effective engagement can minimise curriculum overload and maximise opportunities for flexibility, autonomy, and equity. In mathematics, effective engagement can also ensure that the curriculum is relevant to students and their future lives and work.

2. **Student agency**: curriculum should be designed around students to motivate them and respect their prior knowledge, skills, attitudes and values. For self-directed learning to be incorporated into curriculum design, students' motivations and interests should be considered.

3. **Teacher agency**: teachers should be empowered to use their professional knowledge, skills and expertise to deliver the curriculum effectively. Teacher engagement in curriculum redesign and implementation in mathematics, and providing relevant and appropriate levels of support, ensure that students' experience of the curriculum meets their needs and interests.

6. Next Steps

The E2030 Project will soon release an international mathematics curriculum analysis report that will describe various countries' experiences with mathematics curriculum reform. In particular, the report will discuss how a mathematics curriculum is different from that of other learning areas or subjects, how it has evolved in the past and what kinds of changes are introduced in recent years, what kinds of challenges different countries face in doing so, as well as policy implications for a future mathematics curriculum reform.

To illustrate these curriculum changes and trends with concrete examples from classrooms, we wish to co-produce this report by inviting contributors, in particular, academic experts with their latest research on mathematics curriculum as well as teachers and students with their classroom level experiences. If readers are interested in contributing, please contact the OECD E2030 Project Secretariat at education2030@oecd.org. Our curriculum analyses reports have benefited from insights of multiple perspectives (policy-makers, curriculum designers, mathematics experts, school leaders, teachers, teacher educators, students, teachers-to-be) (OECD, 2020[37]; OECD, 2020[60]; OECD, 2021[61]; OECD, 2021[62]), so we wish to do the same for the forthcoming mathematics report.

With this position paper, the forthcoming publication along with and other E2030 mathematics-related studies[4], we aim at working with a wide range of stakeholders (policy makers, curriculum designers, math experts, teachers, students, teacher educators, etc.) towards making mathematics education more future-oriented and relevant for our students who can shape a better future.

[4] Specifically, the MCDA (Mathematics Curriculum Document Analysis) and CCM (Curriculum Content Mapping) studies as described in the introduction session of this paper.

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Annex 2: List of constructs currently reviewed

The following constructs are currently under review based on the following guiding principles:

- **Clear definition**: Does the construct have a commonly used and understood definition?
- **Relevant for 2030**: Does the construct, alone or in combination with others, equip people for future challenges?
- **Interdependent**: Can we say how the construct develops in conjunction with others?
- **Impactful**: Is the construct proven to have a bearing on future life outcomes?
- **Malleable**: Can the construct be developed through the processes of learning?
- **Measurable**: Can the construct be given a comparative numerical value on a scale, or a non-numerical account?

The list is not exhaustive but constructs are selected that are closely related to the key concepts underpinning the framework.

- Adaptability/ Flexibility/ Adjustment/ Agility
- Cognitive flexibility
- Compassion
- Conflict resolution
- Creativity/ Creative thinking/ Inventive thinking
- Critical-thinking skills
- Curiosity
- Empathy
- Engagement/Communication skills/Collaboration skills
- Equality/ Equity
- Global mind-set
- Goal orientation and completion (e.g. grit, persistence)
- Gratitude
- Growth mind-set
- Hope
- Human dignity
- Identity/Spiritual identity
- Integrity
- Justice
- Manual skills for information and communication technology (related to learning strategies)
- Manual skills related to the arts and crafts, music, physical education skills needed for the future

- Meta-learning skills (including learning to learn skills)
- Mindfulness
- Motivation (e.g. to learn, to contribute to society)
- Open mind-set (to others, new ideas, new experiences)
- Perspective-taking and cognitive flexibility
- Pro-activeness
- Problem solving skills
- Purposefulness
- Reflective thinking/Evaluating/Monitoring
- Resilience/Stress resistance
- Respect (for self, others, including cultural diversity)
- Responsibility (including locus of control)
- Risk management
- Self-awareness/Self-regulation/Self-control
- Self-efficacy/Positive self-orientation
- Self-worth
- Tolerance of ambiguity
- Trust (in self, others, institutions)

THE FUTURE OF EDUCATION AND SKILLS

OECD Learning Compass for Mathematics

Schools are facing increasing demands to prepare students for rapid economic, environmental and social changes, for jobs that have not yet been created, for technologies that have not yet been invented, and to solve social problems that have not yet been anticipated. Underpinning the E2030 project is the premise that education needs to do more than prepare young people for the world of work. It also needs to equip them with the knowledge, skills, attitudes and values they need to become active, responsible and engaged citizens.

Within the broader context of educational outcomes, mathematical thinking and reasoning are increasingly pertinent to the economic, political and social life in the 21st century and beyond. Mathematical thinking and reasoning are used in a growing range of occupations and are becoming increasingly significant in new opportunities for human advancement. For example, Artificial Intelligence (AI) requires complex algorithms, computer simulations and analyses of large amounts of data for economic, scientific, and social planning, all require the application of mathematical knowledge and skills.

This OECD Education 2030 position paper considers the challenges that young people will face; suggests the importance of the concept of learner agency; proposes an overarching learning framework with transformative competencies; reviews the nature of the knowledge, skills, attitudes and values that are applicable to mathematics education; and ends with possible curriculum design principles. It encapsulates the key messages of the project so far.

Do you want to take part in OECD Education 2030?

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