Scientific literacy – what can we learn from high performing jurisdictions?

Research Report

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Contents

Executive Summary

This report presents a literature review that was conducted to answer the question – what can we learn from high performing jurisdictions with respect to scientific literacy? The review intends to build a picture of the education systems, specifically science education, in the five jurisdictions which performed the best in the scientific literacy component of the latest (2018) PISA assessment. These include (in order of best performance, starting with the first: mainland China (Beijing, Shanghai, Jiangsu, Zhejiang), Macao (Special Administrative Region of China or S.A.R.), Singapore, Japan and Estonia.

Information collated through the literature review was analysed and themes that emerged from the literature were picked out. The report breaks down the findings of each jurisdiction into key themes, starting with the *general education system*, which is further sub-divided into important themes such as: stages of education, centralisation of education, curricular reforms. It then talks about each jurisdiction's *science-specific features*, further dividing it into sub-themes such as: when students study science and the ages at which science is compulsory, the influence of research on science education, features and aims of the science curriculum.

The discussion is centred around commonalities and differences that emerged from the themes. For instance, it became clear that inquiry approaches in teaching and learning were a key pedagogical approach mentioned across the jurisdictions, but that evidence around its use was mixed and inconsistent. Another common theme was that at least two jurisdictions talked about the importance of research in informing curriculum development. Another important theme was that many jurisdictions appear to have high quality teacher training and professional development opportunities. For instance, mainland China, Japan, and Estonia have high entry requirements for those wanting to enter teacher training courses. Teachers in some of these high performing jurisdictions are also highly encouraged to participate in professional development and training. E.g., The OECD Teaching and Learning International Survey (TALIS) results suggest that teachers in Japan take part in continuing professional development more than the average (OECD, 2014 as cited in Isozaki, 2018). In Singapore, teachers can receive financial support to study at Master's and doctoral levels (Zuljan & Vogrinc, 2011; NIE, 2013 as cited in Tonga et al., 2019).

However, there were also some differences between the jurisdictions that stood out. For instance, Macao S.A.R[1]. (in contrast to mainland China, Singapore, and Japan) appears to have a highly de-centralised education system in contrast to other jurisdictions, with a large proportion of private schools, which do not have to adhere to one curriculum, unlike more centralised jurisdictions.

It is important to note that although this review identified some themes around scientific literacy that may be common to high performing jurisdictions, it does not mean that these contribute to or cause their high performance. There are other factors that may also be important, such as attitudes towards science learning or parental support. These were not included in this review. Also, each jurisdiction has its own history, culture and socio-

[1] Please note, that this report may in places refer to Macao S.A.R. as Macao.

economic climate, which need to be considered in detail when trying to unpick education systems. We cannot forget that every education and curriculum system is embedded within a wider social space that contributes to the system. This means that we cannot assume that specific factors make some jurisdictions perform better than others on international assessments like PISA. It also cautions against uninformed policy borrowing and implantation (Lau & Lam, 2017; Oates, 2013).

Introduction

There is great interest in the performance of jurisdictions on international assessments, such as the Programme for International Student Assessment (PISA) or the Trends in International Mathematics and Science Study (TIMSS). These initiatives have a large influence on educational policies and systems worldwide (Deng & Gopinathan, 2016). Jurisdictions that perform highly on these assessments (also known as 'strong performers', 'top-performing systems', high performing jurisdictions [HPJs] or high performing education systems [HPES]) are often believed to have a "secret formula" for their educational success linked to the quality of teachers, school leadership and educational reforms (Deng & Gopinathan, 2016, p. 1 & 4). Educational specialists, policy makers and researchers often look at high performing jurisdictions for ideas on how to improve educational performance in their own jurisdictions. This can sometimes lead to curriculum and policy borrowing[2]. Jurisdictions often look at the "methods, techniques and theories utilised by high-achieving jurisdictions in order to achieve better academic success and a sound education system" (Maya & Yilmaz, 2017, as cited in Tonga et al., 2019, p. 98).

East Asian jurisdictions have tended to perform well in the science component of PISA, which has encouraged questions around "what counts as 'good' science education" (Lau, 2014, p. 2). In this report, I reviewed the literature into science education and curricula of the five jurisdictions that performed the highest in the 2018 PISA science assessment: mainland China (in this case Beijing, Shanghai, Jiangsu, Zhejiang or B, S, J, Z), Macao S.A.R., also known as Macau), Singapore, Japan and Estonia. Macao has its own section, as the PISA assessment reported Macao to be the third highest performing jurisdiction in scientific literacy, therefore it appeared to report it separately. Additionally, Macao does not have the same education system as mainland China (e.g., Scholaro, n.d.a; Scholaro, n.d.b). The report outlines the definition of scientific literacy as presented in the PISA assessment, summarises literature into science education and curriculum at primary and secondary levels in these jurisdictions, suggests what can be learnt from HPJs on the topic of scientific literacy, and highlights important considerations around drawing conclusions from international comparisons. Throughout this report, 'mainland China' and 'China' will be used interchangeably.

Relevant literature on these five jurisdictions and their performance on PISA was analysed and highlighted some common questions (themes) that cropped up across the jurisdictions. This report presents information on these themes for each jurisdiction. For the general

[2] 'Policy borrowing' refers to investigating "aspects of education in other countries … to identify what contributes to success in the hope that lessons might be learnt which could have implications for policy development in the 'home' context" (Phillips & Ochs, 2004, p. 773).

education system, the themes include: the age of starting and ending various stages of education, the types of schools in each system, length of compulsory education, mother tongue in each system, language(s) of instruction, key dates in the development of national curricula and key features of the national curricula of each system, how centralised each education system is, the use of textbooks and resources, availability of technology and the influence of culture/social factors on each system. Also, key themes about each jurisdiction's science education are presented, including: groups who contributed to the development of the national curriculum, whether science is compulsory or elective, teaching/contact/learning hours, science opportunities outside of school, importance of research in curriculum/teaching/learning, key aims and features of the science curriculum of each system (e.g., competencies, focus on lower or higher levels of cognitions), place of scientific literacy in the curriculum, teacher training and development, teaching approaches (e.g., inquiry-based teaching/learning), and curriculum areas where students perform well in PISA.

The above elements of educational systems which are considered in this report are similar to the control factors outlined by Oates (2013). Control factors provide useful categories for looking at other systems and their policy arrangements and include: curriculum content (e.g., textbooks, support materials), assessment and qualifications, national framework (e.g., routes, qualifications), inspections, pedagogy, professional development (levels and nature of teacher experience), institutional development, institutional forms and structures (e.g., education phases), allied social measures (e.g., those that link social care, health and education), funding, governance (autonomy vs direct control), accountability arrangements, selection and gatekeeping (e.g., university admission requirements) and labour market regulation (linked to vocational qualifications).

Analysis of the literature across the jurisdictions showed that there are features of education systems which may be important to consider when unpicking high performance in scientific literacy in PISA, including:

- an emphasis on scientific literacy in the curriculum,
- using research evidence in curriculum development,
- a strong system of teacher training, including university level initial training, in-service training and continuing professional development.

It is vital to highlight that this is not an exhaustive list of the features which facilitate high performance in scientific literacy. They cannot be injected into an education system as a magic formula for high performance in scientific literacy, either individually or as a bundle. Also, co-occurrence between high performance in PISA and certain features of an education system does not mean that those features *cause* high attainment. It could be that high achievement in scientific literacy enables a jurisdiction to include these features in their education system. However, the listed features are elements which may form part of a strong science education system.

There were also key differences between the education systems, which suggests that these factors may not be as influential in facilitating high achievement in scientific literacy or that more research and evidence is needed to understand their contribution, such as:

- the presence and extent of inquiry-based learning in the curriculum and lessons,
- whether the education system is highly centralised or de-centralised.

It is crucial to note that the two sets of bullet points are not exhaustive, for various reasons including that the literature does not cover every aspect of education systems, and that it was beyond the scope of the study to analyse the national curriculum documents or conduct in-jurisdiction data collection.

The Programme for International Student Assessment (PISA)

The PISA initiative is organised by the OECD and occurs every three years. It assesses 15-year-olds' abilities in reading, mathematics and science, and their ability to "address real-life challenges" (Department for Education [DfE] & National Foundation for Educational Research [NFER], 2019, p. 2). The assessment "examines how well students can extrapolate from what they have learned and can apply that knowledge in unfamiliar settings" (OECD, 2019a, p. 11). Each round of PISA focuses on one of the three main domains (for instance, reading proficiency was the major domain in 2018), but all three domains are assessed in every round. Almost 80 jurisdictions participated in the 2018 round of PISA (DfE & NFER, 2019). PISA is a computer-based assessment, although paper-based assessments are offered to countries which prefer to use those. The paper-based exam was limited to the three core domains of science, maths and reading, therefore newer items were designed only for the computer-based version. The assessment lasts approximately 2 hours for each student. It includes a mixture of multiple-choice questions and open-response questions and reportedly "stringent quality-assurance mechanisms are applied in translation, sampling and data collection" to ensure validity and reliability of collected responses (OECD, 2019a, p. 13). Different forms of the test were available for countries that took part in the global competence assessment (an innovative domain that is also assessed and in 2018 it was called *global competence*). In 2018, there was an option to assess financial literacy (based on the same framework developed in 2012, which was also used in 2015). To collect wider information, PISA also asks students and school principals to answer context questionnaires. These take about 40 minutes and provide information on the "student, school and system performance" (OECD, 2019a, p. 17).

In 2018, five additional questionnaires were available as options, including: the computer familiarity questionnaire (which assessed the availability and use of ICT and students' ability in doing computer tasks as well as attitudes to computer use), the well-being questionnaire (which assessed students' views of their own health, life satisfaction and social connections), educational career questionnaire (which assessed areas such as school interruptions, preparation for careers, support with language learning), parent questionnaire (which assessed parents' views and involvement in their child's schooling, support at home, school choice, background and career aspirations), and teacher questionnaire (which assessed teachers' initial training and professional development, attitudes and beliefs, and teaching practices). The OECD states that together with information collected through various questionnaires sent to students, principals (and optional ones for parents and teachers), PISA provides three main outcomes:

- "basic indicators that provide a profile of the knowledge and skills of students,

- indicators derived from the questionnaires that show how such skills relate to various demographic, social, economic and educational variables,
- indicators on trends that show changes in outcomes and their distributions, and in relationships between student-, school- and system-level background variables and outcomes." (OECD, 2019a, p. 11)

The report also states that policy makers use PISA outcomes to compare the knowledge and skills of the students in their jurisdiction to students in other participating jurisdictions. This can be used for "establishing benchmarks for improvements in the education provided and/or in learning outcomes and understand the relative strengths and weaknesses of their own education system" (OECD, 2019a, p. 11).

Scientific literacy in PISA

The OECD defines the concept of literacy as an innovative concept which refers to "students' capacity to apply knowledge and skills, and to analyse, reason and communicate effectively as they identify, interpret and solve problems in a variety of situations" (OECD, 2019a, p. 13). Scientific literacy is further defined as:

> "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically. (OECD, 2019a, p. 15)"

Scientific literacy also requires "knowledge of common procedures and practices associated with scientific enquiry and how these enable science to advance" (OECD, 2019a, p. 98). The definitions of literacy and scientific literacy thus appear to emphasise skills, such as application, analysis, interpretation, and evaluation, in addition to possessing knowledge. Scientific literacy was a major domain assessed in the 2006 and 2015 PISA, and a minor domain in the latest 2018 assessment (OECD, 2019a & 2019b).

Scientific literacy in the 2015/2018 PISA assessment is defined by the following competencies:

- "explaining phenomena scientifically (being able to recognise, give and evaluate explanations for various natural and technological phenomena),
- evaluating and designing scientific enquiry (being able to describe and assess scientific investigations and suggest ways of addressing questions scientifically), and
- interpreting data and evidence scientifically (being able to analyse and evaluate data, claims and arguments in different representations, and draw appropriate conclusions)." (OECD, 2019a, p. 99-100)

It is assessed through questions linked to the following three interrelated elements:

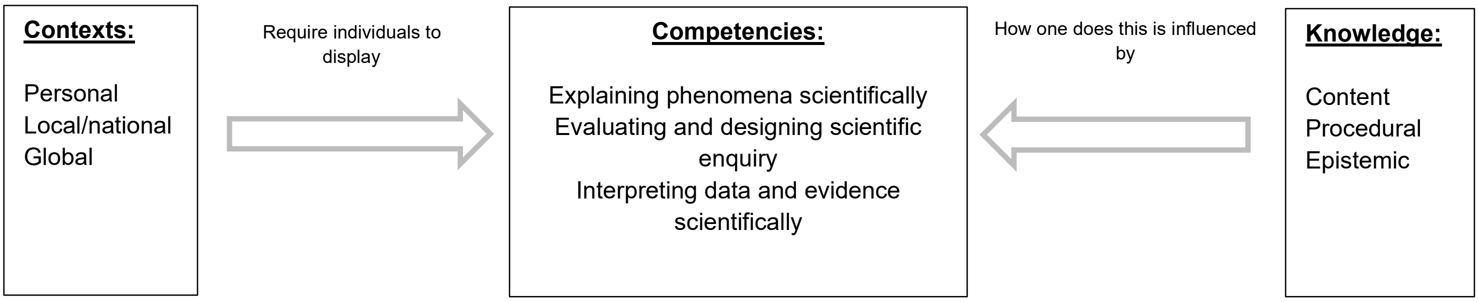
- Contexts - including personal, historical and current national/local/global issues which require some understanding of science and technology (see Table 1 for more detail),
- Knowledge - which requires understanding of key facts, concepts and theories that form the basis of scientific knowledge. This includes knowledge of the natural world

and technology (content knowledge), knowledge of how ideas are produced (procedural knowledge), and understanding of the underlying rationale for these procedures and justifications for their use (epistemic knowledge) (see Table 2 for more detail),

- Competencies – being able to explain phenomena scientifically, interpret evidence and data scientifically, evaluate and design scientific enquiry and evaluate if conclusions are warranted (OECD 2019a).

Figure 1

Inter-relations between the three elements (OECD, 2019a, p. 103)



Items in the scientific literacy component of the 2018 PISA

The scientific component of PISA 2018 assessed scientific knowledge through contexts that raised important issues relevant to the science education curricula of jurisdictions participating in PISA. Items can relate to personal concepts of the self, family and peer groups and do not necessarily have to be limited to school science contexts. For instance, they may assess understanding of the processes or practices involved in advancing science knowledge. The science component “assesses competencies and knowledge in specific contexts” (OECD, 2019a, p. 103). The contexts for items assessing scientific literacy have been grouped into five applications of science and technology: *health and disease, natural resources, environmental quality, hazards* and *the frontiers of science and technology* (Table 1).

Table 1

Contexts for the PISA 2018 scientific literacy assessment

	Personal	**Local/national**	**Global**
Health and disease	Maintenance of health, accidents, nutrition	Control of disease, food choices, community health	Epidemics, spread of infectious diseases
Natural resources	Personal consumption of materials and energy	Maintenance of human populations, quality of life, security, production and	Renewable and non-renewable natural systems, population growth, sustainable use of species

		distribution of food, energy supply	
Environmental quality	Environmentally friendly actions, use and disposal of materials and devices	Population distribution, disposal of waste, environmental impact	Biodiversity, ecological sustainability, control of pollution, production and loss of soil/biomass
Hazards	Risk assessments of lifestyle choices	Rapid changes (e.g., earthquakes, severe weather), slow and progressive changes (e.g., coastal erosion, sedimentation), risk assessment	Climate change, impact of modern communication
Frontiers of science and technology	Scientific aspects of hobbies, personal technology, music and sporting activities	New materials, devices and processes, genetic modifications, health technology, transport	Extinction of species, exploration of space, origin and structure of the Universe

Taken from OECD, 2019a, p. 103

In addition to context, one of the elements assessed in the scientific literacy component of PISA is knowledge. The three types of knowledge found in the assessment are: content, procedural and epistemic knowledge, as mentioned above. Table 2 presents more information about each knowledge type.

Table 2

Types of knowledge assessed in PISA 2018 science component

Content knowledge	**Procedural knowledge**	**Epistemic knowledge**
The assessed content knowledge is taken from the main fields of biology, physics, chemistry, earth and space sciences. It is relevant to everyday situations, represents important scientific concepts and is appropriate to the developmental level of 15-year-olds	Refers to knowledge of standard concepts and procedures in scientific enquiry, which underpin collecting, analysing and interpreting scientific data and information. This knowledge is needed to undertake scientific enquiry and to engage in a critical review of evidence, which may also be used to support scientific claims.	Refers to knowledge of the constructs and key features required for the process of knowledge building (such as hypotheses, observations, theories). Students use this type of knowledge to explain differences between scientific facts and observations, and in understanding the construction of models. Epistemic knowledge provides justification for the procedures and practices that scientists engage in.
Physical systems including: Structure of matter (e.g., particle model, bonds) Properties of matter (e.g., changes of state, thermal and electrical conductivity)	Examples of tested concepts: The concept of variables, including dependent, independent and control variables	The constructs and defining features of science, that is: The nature of scientific observations, facts, hypotheses, models and theories

<table>
<tr>
<td>Chemical changes of matter (e.g., chemical reactions, energy transfer, acids/bases)

Motion and forces (e.g., velocity, friction) and action at a distance (e.g., magnetic, gravitational and electrostatic forces)

Energy and its transformation (e.g., conservation, dissipation, chemical reactions)

Interactions between energy and matter (e.g., light and radio waves, sound and seismic waves)</td>
<td rowspan="2">Concepts of measurement, e.g., quantitative measurements, qualitative observations, the use of a scale or other instruments, categorical and continuous variables

Ways of assessing and minimising uncertainty such as repeating and averaging measurements

Mechanisms to ensure the replicability (closeness of agreement between repeated measurements of the same quantity) and accuracy (the closeness of agreement between a measured quantity and its true value) of measurements

Common ways of abstracting and representing data using tables, graphs and charts and their appropriate use;
The control of variables and its role in experimental design

The use of randomised controlled trials to avoid confounded findings and to identify possible causal mechanisms;
The nature of an appropriate design for a given scientific question, e.g., experimental, field-based or pattern-seeking.</td>
<td>The purpose and goals of science (to produce explanations of the natural world) as distinguished from technology (to produce an optimal solution to human need), what constitutes a scientific or technological question, and what constitutes appropriate data

The values of science, such as a commitment to publication, objectivity and the elimination of bias

The nature of reasoning used in science, such as deductive, inductive, inference to the best explanation (abductive), analogical and model-based</td>
</tr>
<tr>
<td><u>Living systems, including:</u>
Cells (e.g., structures and function, DNA, differences between plant and animal cells)

The concept of an organism (e.g., unicellular vs. multicellular)

Humans (e.g., health; nutrition; subsystems such as the digestive, the respiratory, the circulatory, the excretory and the reproductive and their relationship)

Populations (e.g., species, evolution, biodiversity, genetic variation)

Ecosystems (e.g., food chains, matter and energy flow)

Biosphere (e.g., ecosystem services, sustainability)

<u>Earth and space systems, including:</u>
Structures of the Earth (e.g., lithosphere, atmosphere, hydrosphere)

Energy in the Earth (e.g., sources, global climate)

Change in the Earth (e.g., plate tectonics, geochemical</td>
<td><u>The role of these constructs and features in justifying the knowledge produced by science, that is:</u>
How scientific claims are supported by data and reasoning in science

The function of different forms of empirical enquiry in establishing knowledge, including both their goal (to test explanatory hypotheses or identify patterns) and their design (observation, controlled experiments, correlational studies)

How measurement error affects the degree of confidence in scientific knowledge

The use and role of physical, system and abstract models and their limits

The role of collaboration and critique and how peer review helps to establish confidence in scientific claims

The role of scientific knowledge, along with other forms of knowledge, in identifying and addressing societal and technological issues</td>
</tr>
</table>

cycles, constructive and destructive forces) Earth's history (e.g., fossils, origin and evolution) Earth in space (e.g., gravity, solar systems, galaxies) The history and scale of the Universe and its history (e.g., light year, Big Bang theory)		

Adapted from OECD (2019a), pp. 106-108.

How does the scientific literacy component in PISA compare to what is assessed in GCSE science qualifications?

With regards to how the GCSE qualification compares to what is assessed in PISA, the GCSE biology, chemistry and physics GCSE subject content (DfE, 2015) shows some similar aims to those outlined above. The GCSE subject content document says that studying sciences offers basics for understanding the material world, and that scientific understanding is important to our future, so all students should be taught aspects of science knowledge, methods, processes and uses of science. The document further states that GCSE specifications in the sciences should support students to:

- "develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics,
- develop understanding of the nature, processes and methods of science, through different types of scientific enquiries that help them to answer scientific questions about the world around them,
- develop and learn to apply observational, practical, modelling, enquiry and problem-solving skills, both in the laboratory, in the field and in other learning environments,
- develop their ability to evaluate claims based on science through critical analysis of the methodology, evidence and conclusions, both qualitatively and quantitatively" (p. 5).

The document then talks about how working scientifically should be developed and assessed through developing scientific thinking, experimental skills and strategies, analysis and evaluation and scientific vocabulary, quantities, units, symbols and nomenclature. It then sets out the key elements and content for biology, chemistry and physics.

The GCSE science qualifications in England are assessed through "terminal, written examinations". Students are involved in practicals (standard experiments) that they need to know about, but these are also assessed in the written examinations that students sit. "There is no practical assessment in class" which counts towards the final GCSE grade. All of the versions of GCSE science follow this model of assessment, but what might vary is the number of written examinations that students sit (T. Gould, personal communication, August 22, 2022).

At an overall glance, there may be some similarities in elements of the PISA assessment and the GCSE science assessment. For instance, the final bullet point above emphasises evaluation skills and critical analysis skills in GCSE science, which is somewhat similar to one of the competencies assessed in PISA, namely “being able to explain phenomena scientifically, interpret evidence and data scientifically, evaluate and design scientific enquiry and evaluate if conclusions are warranted” (OECD, 2019a), which also emphasises evaluation.

Although I did not compare content closely, there appear to be some similarities in terms of what is assessed in PISA and the GCSE assessments. For example, the GCSE curriculum document specifies that students should “develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics”. The PISA assessment also assesses content knowledge taken from biology, chemistry and physics. For instance, ‘living systems’ such as cells, concepts of organisms and ecosystems are taken from biology. In the GCSE qualification, some of the outlined biology content includes the fundamental units of living organisms (cells), characteristics of living organisms influenced by its genome and interactions with the environment. However, the document also states that awarding bodies “may use flexibility to increase the breadth or context within the specified topics” (DfE, 2015, p. 9).

One small difference, but also a similarity between the PISA assessment and the GCSE science document is that some of the content assessed in PISA is taken from earth and space science, such as gravity or solar systems (see Table 2, content knowledge: “the assessed content knowledge is taken from the main fields of biology, physics, chemistry, <u>earth and space sciences</u>). Earth science(s) refer to the study of the solid Earth, its waters and the air around it. It includes “the geologic, hydrologic, and atmospheric sciences” (Albritton, n.d., para 1). The GCSE subject content guide for Biology, Chemistry and Physics lists “<u>Earth and atmospheric science</u>” as one of the content areas that students need to cover in Chemistry. Although these areas (highlighted) are labelled slightly differently, they both talk about the structure of the Earth, including the atmosphere and how it was formed. However, the PISA assessment states the content in very generalist terms, e.g., “Energy in the Earth (e.g., sources, global climate)” (OECD, 2019a, p. 106). It is difficult to interpret if there is overlap with the content of the GCSE subject guide because of this generalist terminology. It is beyond the scope of this report to examine the items included in PISA to comment on their similarity to the content covered at GCSE level in science.

There are, however, important differences between the GCSE qualification and the PISA assessment. The key difference is that GCSE examinations are seen as being high-stakes, as they can determine opportunities that learners may be presented with in the future, such as being accepted for specific Level 3 courses, university-level courses and jobs. For instance, Jerrim (2022) found that those who achieved a ‘good pass’ (grace 4/C) in mathematics were round 5 percentage points more likely to hold a university degree by the age of 26 than individuals who did not meet this threshold. In contrast, the PISA assessment aims to “assess the extent to which 15-year-old students, near the end of their compulsory education, have acquired key knowledge and skills that are essential for full participation in modern societies” (OECD, 2017, p. 12). However, the PISA assessment does not judge individual students on their performance, and outcomes are not seen as high stakes, as they do not determine students' future options, unlike the GCSE assessment. PISA performance provides a more high-level overview of what 15-year-olds in different countries can do, and how countries compare to each other.

It appears that there may be some similarities between the scientific literacy component of the PISA assessment and what is assessed at GCSE level in science, with respect to the content and skills assessed, but this review cannot compare the two in a lot of detail and offers only very high-level, generalist comments. However, there are also important differences between the GCSE and PISA assessment, including higher stakes of the GCSE assessment. There may also be differences in the individual items that are assessed in the GCSE and PISA, but this is beyond the scope of this report. It is crucial to remember that there are curriculum documents for other science subjects in England, such as Combined Science, which may also be of interest, therefore this could form an area for future research in this space. Furthermore, each country will have different qualifications at GCSE level (or similar), thus it is impossible to say how similar or different the scientific literacy component is to what is assessed at GCSE-equivalent level in other countries. This would need to be investigated further by subject and country specialists. It is beyond the scope of this report to comprehensively compare science GCSE-level qualifications with the PISA assessment for the reasons outlined.

Jurisdiction performance in PISA 2018

There are six proficiency levels, which are used to report performance in scientific literacy, starting at Level 1 (lowest) and ending on Level 6 (highest). Level 2 is seen as the "baseline level of scientific literacy" and it suggests "the level of achievement on the PISA scale at which students begin to demonstrate the scientific knowledge and skills that will enable them to participate actively in life situations related to science and technology" (OECD, 2013, p. 113).

The OECD reported that on average, 78% of learners from OECD jurisdictions attained Level 2 or higher in science. This means that these students "can recognise the correct explanation for familiar scientific phenomena and can use such knowledge to identify, in simple cases, whether a conclusion is valid based on the data provided" (OECD, 2019b, p. 15).

The top five performing jurisdictions in the science domain of the 2018 PISA were:

- Mainland China (B, S, J, Z) (mean score of 590 points),
- Macao S.A.R. (China) (mean score of 544 points),
- Singapore (mean score of 551 points),
- Japan (mean score of 529 points) and
- Estonia (mean score of 530 points) (Schleicher, 2019).

Over 90% of learners in China (B, S, J, Z) (97.9%), Macao S.A.R. (94%), Estonia (91.2%) and Singapore (91%) achieved the Level 2 benchmark and many students from these HPJs achieved proficiency Level 5 or 6 in science (32% of students in China and 21% of students in Singapore performed at these high levels) (OECD, 2019b).

Literature review

I carried out a review of existing literature reporting on science education and curricula in the five top performing PISA jurisdictions. To find relevant sources, search engines such as Google Scholar, ERIC and Science Direct were used and key terms related to scientific literacy and performance were entered into these databases. Examples of key words entered include: “science+literacy+Estonia”, “science+teaching+Japan”, “science+curriculum+China”, “scientific+literacy+PISA+2018”. Governmental and organisation websites were also investigated for sources.

The literature search focused on research from 2010. This is because students aged 15-years-old in 2018 would have started primary education around 2010 and thus would have experienced both primary and secondary education by 2018. It is also important because effects of policy changes or changes to science teaching would need several years to become visible in the classroom, thus starting in 2010 would potentially allow research to capture some educational changes. However, some research from before 2010 was included if it was deemed suitable and important, for instance, when defining scientific literacy or investigating curriculum reform. Literature was included in the review if it talked about areas related to science education and scientific literacy, for instance: the science curriculum in jurisdictions of interest, science education, teaching practices, PISA assessment in relation to primary or secondary level of education (or both).

Sources were analysed for key themes and mentions of possible contributions to the jurisdictions’ high performance in PISA. Information about sources was kept in an Excel spreadsheet, where columns represented specifics of each paper (e.g., jurisdiction, areas of focus of the paper, whether the paper related to curriculum, practice or both, key findings about scientific literacy etc.). This was done to break down each source and to make it easier to interpret each source’s findings with regards to scientific literacy.

It is important to keep in mind that the sources used could vary in how trustworthy and accurate they are. Although most of sources used are peer-reviewed research articles, certain websites from organisations such as the NCEE and TIMS & PIRLS International Study Center were also used. On occasions, I also used blogs and websites if there was no research evidence or official governmental websites to support ideas, e.g., a blog by Gruijters (2020).

Analysis of the literature

Some of the collected literature talked about PISA and jurisdictions’ profiles, therefore it did not specifically mention scientific literacy or science education, but helped to build an overview of each jurisdiction, their curriculum, school system and history. Some sources mentioned other jurisdictions, which were not in the top five that this paper focuses on. In these instances, only the jurisdiction/s of interest were considered in the literature review.

Overall, 29 sources were included in the in-depth analysis and review, but other sources were also used to illustrate points. Table 3 breaks down the key investigated sources and Figure 2 shows the proportion of literature that mentioned each nation. The key sources (presented in Table 3) comprised of academic literature, including peer-reviewed papers and book chapters. However, additional sources were used to confirm certain findings or to support points if peer-reviewed literature was not available. This includes websites and blogs. Table 3 presents specific sources that were important to this review, but (as can be seen in the references section), many other sources were used in this report. Curriculum documents were not included in the analysis, as this would require subject expertise and an in-depth understanding of each jurisdiction's national curriculum. It is important to note that the literature available was not consistent in the information that it provides, and the level of detail varied between sources. The following sections may therefore differ in the level of detail they offer on the five jurisdictions.

Table 3

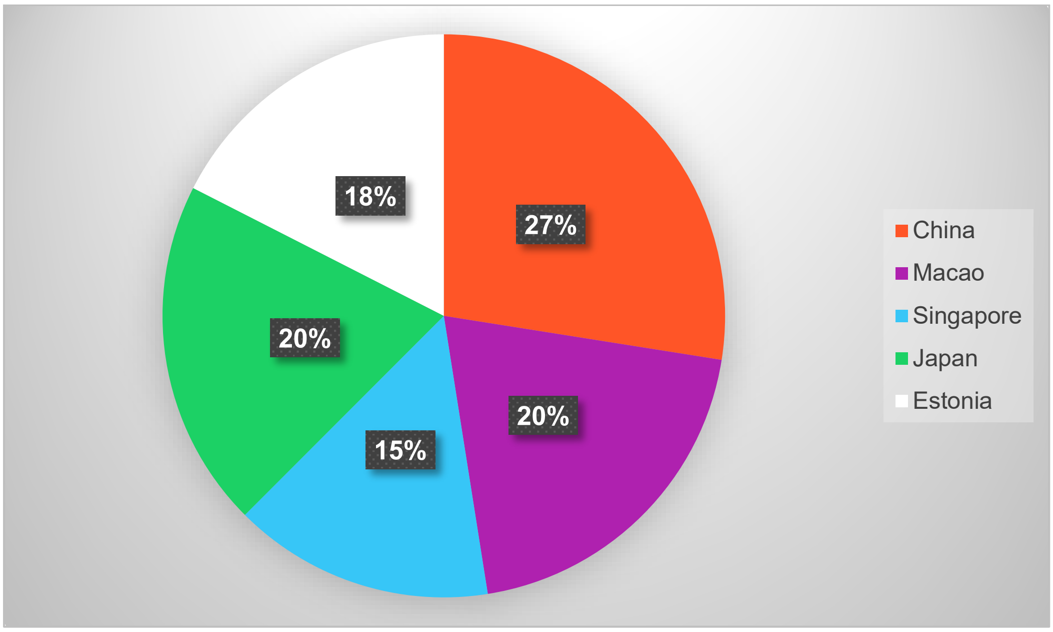
A table illustrating the key sources that were examined for each HPJ

Author(s)	**Year of**	**Jurisdictions mentioned in the publication**
Cui & Zhu	2014	Mainland China
Halpin	2010	
Ma	2016	
OECD	2016a	
Pei	2019	
Wang et al.	2019	
Yao & Guo	2018	
Eurydice	n.d. b	Estonia
Henno & Reiska	2013	
Kori	2022	
NCEE	n.d.a	
Tire	2021	
Isozaki	2018	Japan
Kumano	2009	
NCEE	n.d.b	
Nakamichi & Katayama	2018	
TIMSS & PIRLS International Study Center	n.d.	
Lo You Chun	2005	Macao S.A.R.
Wei	2019	
Wei	2016	
Wei et al.	2020	
Deng & Gopinathan	2016	Singapore
Lee	2018	
Tan et al.	2016	
Lau	2014	Japan, Macao, Singapore
Lau & Lam	2017	Singapore, Japan, Estonia, Macao S.A.R., mainland China
Tang et al.	2020	Macao S.A.R., mainland China
Tonga et al.	2019	Estonia, Japan, Singapore, mainland China
Wei & Ou	2019	Mainland China, Macao S.A.R.

Overall, 27% of the key sources referred to China, 20% referred to Macao and Japan, 18% referred to Estonia and 15% mentioned Singapore (see Figure 2 below).

Figure 2

A pie chart of the examined literature illustrating proportions of mentions of each nation



China was the most prevalent jurisdiction mentioned in the collected literature. When referring to China, the 2018 PISA assessment focuses on Beijing, Shanghai, Jiangsu, and Zhejiang regions. Some of the investigated sources made it clear which regions they were referring to, but others talked about China in general terms or mainland China. A large proportion of the literature did not specify which Chinese regions they were referring to, which made it difficult to filter through the literature for sources that were most relevant. It was easier to find sources investigating China's education system and science curriculum than Japan or Estonia. Some sources talked more broadly about jurisdictions' general education systems rather than their science curricula although efforts were made to focus the literature on science education in given jurisdictions.

The findings section is split into the five HPJs (mainland China, Macao, Singapore, Japan and Estonia). For each jurisdiction, there is a description of the general education system, followed by a description of science education and curriculum in that jurisdiction. Each of the two main sections (general education system and science education and curriculum) has further sub-sections (e.g., place of scientific literacy in the curriculum). These sub-sections emerged from the literature review and were deemed important in building a picture of each jurisdiction's educational landscape around scientific literacy.

Mainland China

General education system

Overview of the jurisdiction

There are over 30 various provinces/municipalities in China (e.g., Grujiters, 2020; WorldAtlas, n.d.a). In various cycles of the PISA assessment, different regions had been used to represent mainland China and its performance. For instance, Beijing, Shanghai, Jiangsu and Guangdong were used to represent China in the 2015 PISA and Beijing, Shanghai, Jiangsu and Zhejiang were used in the 2018 cycle (OECD, 2019b). This has been questioned by some, as these regions tend to be the wealthiest metropolitan areas and may not be representative of all of mainland China (e.g., Gruijters, 2020; Schneider, 2019).

It is important to note that the literature used in this report tended not to mention which Chinese regions were investigated. Most sources tended to refer to ‘mainland China’ or just ‘China’, without specifying if they are referring to all regions or specific ones. We must therefore maintain caution when interpreting the findings of these sources, especially in very large countries like China, which have various regions. This means that some of the information below may refer to areas beyond the four that represented China in the 2018 PISA cycle. This is important to keep in mind when reading the information presented here.

Throughout this report, I use the phrases ‘China’ and mainland China’ interchangeably.

Stages of education

Students in China must complete nine years of compulsory education. The organisation of the Chinese education system at primary and secondary levels includes the following stages:

- pre-school (2-5 years of age) - students may enrol in pre-school, but pre-school education is not compulsory and many pre-schools are privately owned (OECD, 2016a,
- primary school (6-11 years of age or grades 1-6) – most students start primary school at the age of 6- or 7-years olds, and spend six years in primary school, which is compulsory,
- junior (lower) secondary school (12-14 years of age or grades 7-9) – which is compulsory,
- senior (upper) secondary school (15-17 years of age or grades 10-12) – which is not compulsory (OECD, 2016a), but data from 2014 suggests that only about 10% of students graduating from junior secondary schools did not continue their education after compulsory education (National Bureau of Statistics of China, 2014, as cited in OECD, 2016a; Scholaro, n.d.a).

Pre-school, primary school, and secondary school stages make up “basic education” in China (Open University, 2019). Senior secondary education takes a further three years and five types of senior secondary schools exist: general senior secondary, technical (specialised) secondary, adult secondary, vocational and craft secondary (with the last four considered to be vocational secondary schools, OECD, 2016a). A larger proportion of Chinese students attend general senior secondary schools. The government uses performance in a public examination (*Zhongkao*) to assign students to one of the senior secondary schools (OECD, 2016a). At the end of senior secondary school, students who wish to apply to universities sit the National Higher Education Entrance Examination (or the National College Entrance Examination), commonly known as *gaokao* in China (Scholaro, n.d.a).

Languages

Various languages are used in China, and sources sometimes contradict each other in this area. WorldAtlas states that some linguists believe that there are almost 300 living languages in China (n.d.b). According to CIA (n.d.a), the most common language is Standard Chinese or Mandarin, followed by Cantonese and other dialects. Mandarin also appears to be called Standard Mandarin or Standard Chinese by sources (e.g., WorldAtlas, n.d.b). Similarly, Yang et al. (2017) states that in mainland China, Mandarin Chinese is the official language and the language of instruction in schools. Cantonese also has the status of an official language in China according to WorldAtlas (n.d.b). There are also various dialects of Chinese that can be found in different regions of China (ibid). With regards to writing, there are differences between simplified and traditional (complex) Chinese. Traditional Chinese tends to preserve the characters that have been used for thousands of years whereas simplified Chinese includes simplified versions of the traditional Chinese characters (Eriksen Translations, n.d).

Is education centralised or de-centralised?

Halpin (2010) states that China has had a state-mandated curriculum since 1999, although also writes that "it is more accurate to say that it began to develop such a curriculum from that year, its implementation being still very much an on-going matter" (Guan & Meng, 2007 as cited in Halpin, 2010, p. 258). Liu (2017) suggests that the "Chinese education system is a highly centralized one, and any reforms in Chinese education must be understood within such a centralized context" (p. 2). However, the OECD (2016a) states that in most cases, the central government creates policies that set "general goals rather than dictate specific methods. By the time these policies and strategies arrive in schools … they include practical guidelines" (p. 12). Local governments therefore use them to develop more practical policies intended to provide guidance about how to implement reforms and consider various circumstances (OECD, 2016a). Halpin (2010) suggests that there is space for teacher-discretion in selecting curriculum resources, developing schemes of study, school-based curriculum development and experimentation at school level, as well as the "staircase" model of curriculum implementation (central state, provincial educational administrations, schools/teachers).

Curricular reforms and key features of general curriculum

Cui and Zhu (2014) state that the Basic Education Curriculum Reform Outline (trial) (2001) aimed to change from a narrow perspective of teachers transmitting knowledge to learners knowing how to learn and how to develop positive attitudes. It also attempted to change from a narrow to a balanced, integrated and selective curriculum structure, focusing on essential knowledge and skills related to lifelong learning. In addition to these changes, this curriculum reform also encouraged changing from passive, rote learning approaches to more active, problem-solving approaches to enhance students' abilities in problem-solving and information processing and co-operative learning. This 2001 new curriculum framework also encouraged diversification and a shift away from centralisation occurred, promoting collaboration between the central government, schools and local authorities (Cui & Zhu, 2014; OECD, 2016a). In 2011, a renewed version of the educational framework allowing for more flexibility was developed (OECD, 2016a).

According to the Basic Education Curriculum Reform Outline, the curriculum for primary schools should include courses that "encourage all-round development of individual learners" (OECD, 2016a, p. 24). At secondary level, "schools are encouraged to choose comprehensive courses, and to offer optional courses as well" and "the government emphasises that Chinese, art and painting courses in compulsory education should attach more importance to Chinese character (script) writing" (OECD, 2016a, p. 24). In 2010, the Ministry of Education (MoE) developed the National Long-Term Education Reform and Development Plan (2010-2020), which sets out strategic directions for reform and development of education in China at all levels (OECD, 2016a). The current policy aims to build on the 2001 reform to change the curriculum that is focused on "discipline-based knowledge transmission and preparation for examinations" into a curriculum that "encourages student-led enquiry and more comprehensive and balanced learning experiences" (OECD, 2016a, p. 38). Furthermore, the OECD (2016a) proposes that "the aim of China's Basic Education Curriculum Reform is to promote all-round development of students" (p. 23). Emphasis is placed on the moral, intellectual and physical development of students in order to cultivate moral virtues, discipline, culture and ideas. According to Cui and Zhu (2014), this curriculum reform has affected the classroom in a positive way. For instance, teachers may reflect on their classroom practices after teaching and there has been a decrease in dropout rates. Furthermore, innovative approaches to teacher development have emerged, including the "Big Name Teacher Studio" – a scheme where host teachers share their expertise and knowledge by mentoring younger teachers from other schools (p. 3). It is, however, important to say that, despite these reports, it is very difficult to conclude with certainty that the curriculum reform has had the same impact on all schools and teachers. Although teachers may be more likely to reflect on their own teaching, the extent to which this happens and what impact this might have would need to be investigated further.

Textbooks

OECD (2016a) writes that textbooks are approved by the MoE before they are published and used. Textbooks that will be used nationally are reviewed by the National Primary and Secondary School Textbook Review Commission. Textbooks for local use are reviewed by the provincial textbook review commission. Research into textbooks and curriculum is carried out by the National Centre for School Curriculum and Textbook Development, which is affiliated with the MoE (OECD, 2016a). The OECD (2016a) suggests that in 1988, the government in China began to support more diverse interpretations of educational programmes by developing different textbooks based on the same curriculum.

One of the best and most commonly used textbooks in China is published by the Educational Science Publishing House (ESPH). The development and revision of the ESPH science textbooks have been based on the Science and Technology for Children (STC) – a set of science curriculum developed by the National Science Resources Center (Ma, 2016).

The use of technology in education

As every region in China is slightly different, it is difficult to comment on how widespread the availability and use of technology is in all mainland China. For instance, the OECD (2016a) suggests that "the Beijing government puts a lot of emphasis on promoting Internet-based education" and that "education resources can be available everywhere" with the use of the Internet, which can support schools in enhancing their teaching resources (pp. 39-40). In 2012, a website called the Beijing Digital School was started as a governmental project to provide citizens with high quality online educational materials. Teachers and learners can access materials created by famous teachers and can hold discussions on the website. The Jiangsu province upgraded and started to implement new technology throughout the school sector since 2011, as they started to implement the Medium-Long-Term Education Reform and Development Plan 2010-2020 (OECD, 2016a). It has also made school-wide networks and Internet connectivity across the province more widespread. Furthermore, one of the eight traditional subjects in the curriculum is technology.

Equality in education

The OECD (2016a) reports that "the Chinese government has made educational equity in compulsory education a priority" to narrow the gap between rural and urban locations, and that several programmes have been launched to improve poor school conditions in rural areas, including the Rural Primary and Secondary Schools Dilapidated Building Renovation Project (p. 28). Furthermore, in some areas, grade groups have been established in schools. Teachers from the same grade create a group and share all teaching materials, classroom techniques and curriculum timetable to help underdeveloped schools enhance their teaching quality.

Teacher training and professional development

Considering teacher training and professional development, candidates applying for teaching courses in China must complete two assessments: a university entrance exam (which assesses academic achievement in maths, language, and science) and a practice exam (which looks at teaching abilities, interpersonal skills and communication skills) (Mete, 2013 as cited in Tonga et al., 2019). Ding (2015) further suggests that to promote science education reforms, the MoE has taken on the training of teachers. Many universities and colleges have seen many new centres of curriculum reform, and science educators (amongst others) have become teacher trainers. They offer short courses (3-4 weeks usually), consisting of lectures, lesson observations, discussions, and interactions with peers. The OECD (2016a) reports that the government has established a renewal process for teachers' qualification certificates in order to improve the quality of teachers, whereby teachers in pre-schools, public schools, secondary and vocational schools must re-register for their qualification certificate every five years (MoE, 2013, as cited in OECD, 2016a). New teachers must register to receive their certificate within 60 days of finishing their probation, and in order to be registered, applicants must complete and pass and ethics evaluation and annual assessment, complete at least 360 hours of professional development to receive equivalent number of credits (OECD, 2016a).

The influence of culture on education

A very important point to make is that the culture, history and socio-economic climate of each individual jurisdiction needs consideration when interpreting or attempting to build a picture of their education system. China is a very large country with a rich history and many regions that may have differences. It is therefore vital not to assume that the education system, curriculum, its implementation, or research discussing these, are the same across all regions. For instance, the Jiangsu province is one of the most developed ones, and thus has been involved in educational reform pilot experiments (OECD, 2016a). Lau and Lam (2017) also report that “caution is needed to attribute top performance … to particular teaching practices, which are further attributed to particular cultural and social values” and that “a host of factors” other than teaching practices are at play (p. 2145). For instance, the role of the Confucian Heritage Culture (CHC), which is believed to influence the performance of Chinese and other Asian students, has been disputed. This report cannot comment on all historical, cultural, and social aspects of the five jurisdictions of interest, and it highlights the necessity to maintain caution when picking out factors that contribute to high performance.

Science-specific features

When do students study science and when is science compulsory?

Curriculum reform in China has meant that students start learning science earlier (in grade 1) and thus study it for longer (Pei, 2019). Students study science throughout primary school to high school, as it is a compulsory subject (Yao & Guo, 2018). It appears that in primary schools, students study general ‘science’, which then becomes split into physics, chemistry and biology in junior secondary schools (OECD, 2016a), although it is difficult to determine this. Others sources which talk about science in primary schools in mainland China also refer to ‘science’ rather than the three separate courses of biology, chemistry or physics (e.g., Ding, 2015). In senior high schools, students continue to study biology, chemistry and physics (Ding, 2015). In senior high schools, science programmes consist of compulsory courses (taken by all students to develop a common foundation for the development of general core competencies), optional course I (for those who plan on studying science after completing high school) and optional course II (for students who choose to study independently, aiming to offer a broader view of science. Some course II options require optional course I as a prerequisite) (Yao & Guo, 2018). Curriculum changes have meant that in senior high school, the number of elective modules in science has increased. In recent rounds of reforms, the proportion of compulsory credit hours for physics reached 43% of the total number of compulsory credit hours for science (Yao & Guo, 2018).

Influence of research on science education

This review has highlighted that there is a large amount of research dedicated to science education in China. It also showed that research is used to support curriculum development, although Yao and Guo (2018) argue that poor support for science education research is a problem hindering “the intended science curriculum in China” (pp. 1926-1927). The authors do, however, state that a characteristic of science curriculum reform in China is “that frontline researchers, including scientists, science educators, and teaching-researchers … have the right to speak and have a dominant voice… In contrast to Western jurisdictions such as the US and the UK, professional scientists in China, who are sometimes regarded as the guardians of the disciplines, still play a vital role during the formation of the programmatic curriculum of science” (p. 1928). For instance, in 2014, the MoE asked experts to conduct research into “a system of core competences for students’ development and standards for academic quality” (p. 1918). The ‘scientific spirit’ (one of the core competencies) was conceptualised to have three sub-dimensions*: rational thinking, critical questioning* and *scientific inquiry* (“the ability to ask scientific questions, to present conjecture and hypotheses, to design investigation plans and experiments, to obtain and analyse data, to construct explanations based on evidence, and to communicate, evaluate, and reflect on the processes and results of scientific investigation”, pp. 1924-1925).

Yao and Guo (2018) suggest that over the last thirty years, China’s curricula innovations have contributed to its success in science education. Collaborative efforts between science educators, scientists and policy makers have prepared “a school science curriculum system ‘with Chinese characteristics for a new era’” to support students in facing the requirements of the 21st century (p. 1913). Ma (2016) states that the science curriculum in China is based on research often carried out by teams that have extensive experience, such as Science and Technology for Children. Ma (2016) also writes that science textbooks are based on research. For instance, most of the editors-in-chief of the science textbooks in China have taken part in research (e.g., research into American or French science textbooks). The research outcomes have been used to revise textbooks.

Features and aims of the science curriculum

In 2017, the MoE established the *Primary School Science Curriculum Standards for Compulsory Education* and revisions to the science curriculum standards for senior high schools were completed by the end of 2017 (Ministry of Education, P. R. China, 2017e, as cited in Yao & Guo, 2018). According to Yao and Guo (2018), the new science curriculum standards focus on the historical achievements of science education research in China, present an opportunity to follow the development of science education in China and to see “how other international works inform the elements of Chinese science education and how other global contexts of science education may be informed by Chinese science education” (Zeidler, 2017, as cited in Yao & Guo, 2018, p. 1914).

Research in this review has demonstrated other features of the science curriculum in China. For instance, Wei and Ou (2019) compared key curriculum documents of mainland China, Taiwan, Hong Kong and Macao by applying the Revised Bloom’s taxonomy. The authors concluded that conceptual knowledge appeared most frequently in the science standards for grade 7-9 students, followed by procedural knowledge and factual knowledge. They also found that meta-cognitive knowledge (knowledge of cognition, awareness of one’s own cognition) did not appear in the Chinese curriculum, suggesting that the curriculum standards in junior high school attach little importance to meta-cognitive knowledge. The authors concluded that the examined curriculum documents of mainland China and Macao S.A.R. “have low cognitive requirements and emphasize the memory of knowledge in their junior high school science curricula” (p. 1468). “Remember” and “understand” levels featured the most in the documents, suggesting that the learning requirements for low-level cognitive processes are greater than those for high-level processes, like meta-cognition. This may also suggest that conceptual knowledge at the basic “remember” level is seen as more important than higher-level cognitive processes. This may appear not completely compatible with the emphasis on developing students’ scientific literacy and explaining phenomena scientifically, which are key features of the PISA 2015 assessment framework (see Appendix A for more detail). Furthermore, Lau and Lam (2017) analysed the 2015 PISA data of the top ten performing jurisdictions and found that students in China performed well in areas linked to science content, including *explaining phenomena scientifically (EP)* and *content knowledge (CK)* (see Appendix A for more information).

Yao and Guo (2018) suggest three key elements of the science curriculum: scientific spirit, greater emphasis on physics, and core competencies. In the last round of reforms, the curriculum objectives were arranged into a three-dimensional goal system: *scientific knowledge and skills, process and methods,* and *attitudes and values.* The goal system at primary level adopted a four-dimensional goal system: *scientific knowledge, scientific inquiry, scientific attitude* and *science, technology, society and environment.* In contrast to this dimensional goal system, the premise of core competences offered more flexibility for the interpretation of curriculum policy. For instance, the physics curriculum core competences were defined as “the essential characteristics and key abilities that students form through physics education to ensure lifelong development and social development” (MoE, P. R. China, 2017d, as cited in Yao & Guo, 2018, p. 1923). The core competencies of physics, chemistry and biology are presented in the table below (Table 4):

Table 4

The subject core competencies of physics, chemistry and biology

Subjects	Subject core competencies
Physics	big ideas of physics, scientific thinking, scientific inquiry and scientific attitude and responsibility
Chemistry	Macroscopic identification and microscopic analysis; Changes and equilibrium; Evidence-based reasoning and modelling; Scientific inquiry and innovation; Scientific attitude and social responsibility
Biology	Big ideas of biology; Scientific thinking; Scientific inquiry; Social responsibility

Taken from Yao and Guo (2018)

The authors also suggest that another key element of the science curriculum in China is that the new science standards are linked with assessment, going beyond a fragmented way of listing knowledge content and moving towards “output-oriented learning expectations” (Yao & Guo, 2018, p. 1925). For instance, the new science standards in physics integrate content knowledge, scientific thinking and the nature of science into one scientific practice: constructing a model. Pei (2019) further suggests that the 2017 curriculum reforms reflect four key strategies: increasing the length of time that students study science from grade 3 to 1, integrating engineering and technology into science, design of curriculum based on the idea of learning progressions, and using big concepts to guide teaching contents.

Place of scientific literacy in the curriculum

With regards to the place of scientific literacy in the curricula, Wang et al. (2019) compared the Chinese and Finnish primary science curricula (CH-PSC and F-PSC respectively) and found that one of the key tasks of the Chinese curriculum was to develop students’ scientific literacy. The CH-PSC gave reasons as to why science is taught at primary level whereas the

Finnish curriculum did not. Scientific literacy was outlined as a core task in the CH-PSC and appeared in the document 11 times. The Chinese science curriculum also stated specific objectives about what students should know or be able to do, thus addressed learning outcomes, for instance “students should know how to design a research plan if they want to engage in scientific enquiry” (CH-PSC, p. 6) (see Appendix A for more information).

Opportunities for science learning outside of the classroom

Out-of-school opportunities and programmes to support science learning may exist, although this review did not find any specific ones. Ding (2015) reports that almost 20 regions in China are involved in the ‘Learning by Doing’ project (2001) initiated by the China Association for Science and Technology, which encourages children in kindergartens and elementary schools to explore science through hands-on-activities.

Science teaching (pedagogy) and how science is experienced in classrooms

Lau and Lam (2017) analysed the 2015 PISA data, including the scientific literacy component, student and school questionnaire. With regards to the teaching/learning approach adopted in Chinese classrooms, they found that students in China reported that they received individual feedback from teachers more than their counterparts in other HPJs such as Japan, Korea or Finland. They also found that China tended to allow students to express their ideas in classrooms more, and that students in China appeared to engage in experimental design more. Students also answered questions on their teachers’ instructional/teaching practices. Analyses of these found that Chinese teachers scored lower than the OECD average on enquiry-based instruction, but students appeared to be more involved in designing experiments (see Appendix A for more information).

Tang et al. (2020) suggests that China included *inquiry-based teaching* in their reform policies and teaching initiatives, for instance, in their curriculum standards for 1-9 grade students in 2001 and 2022 (Xie, 2014, as cited in Tang et al., 2020), but teachers felt it was time-consuming (Jian & Sun, 2015, cited in Tang et al., 2020). Despite no consensus on the definition of *inquiry-based teaching*, a common view is that it involves hands-on activities, higher order skills and creative thinking, and does not aim to develop basic skills. It has been recommended as an advanced pedagogy to teach mathematics and science (e.g., Sandoval & Reiser, 2004, as cited in Tang et al., 2020). Inquiry-based learning is defined as “a process of discovering new relations between different variables through formulation hypothesis and testing the hypothesis in experiments or by collecting data through observations” (Mäeots et al., 2011, as cited in Kori, 2022, p. 390). It is a student-centred approach that is active and emphasises the use of questioning, critical thinking and problem solving (Savery, 2015, as cited in Kori, 2022). The literature also uses the term “enquiry”. The OECD defines “enquiry” as ‘engaging students in experimentation and hands-on activities, and also about challenging students and encouraging them to develop a conceptual understanding of scientific ideas” (OECD, 2016, as cited in Lau & Lam, 2017, p. 2131). The terms “inquiry” and “enquiry” thus appear to share many similarities and seem to be used interchangeably in the context of this topic.

Tang et al. (2020) analysed data from the 2015 PISA to assess inquiry-based teaching in high and low performing jurisdictions. The authors found that in China, the greater the teacher collaboration, the greater the scores on inquiry-based questions, and that teachers' beliefs about inquiry learning were positively associated with inquiry-based teaching. Despite the mentions of inquiry-based teaching, my review of the literature has provided mixed evidence with regards to the actual use of inquiry as a teaching/learning tool. For instance, Lau and Lam (2017) found that China was below the OECD average in enquiry-based instruction. Furthermore, although inquiry-based teaching may be promoted in curriculum documents or guidance documents, it does not guarantee that teachers will consistently apply inquiry in the classroom. Lau and Lam (2017) reported that one commonality amongst science classrooms of top performing regions such as China, is that teachers tended to spend a substantial amount of time in lessons explaining scientific concepts, in addition to class discussion where students could express their ideas.

Student performance in specific components of science in PISA

It is also worth mentioning some of the curriculum areas where students perform well in PISA. Lau and Lam (2017) found that Chinese students performed well in areas linked to science content, including explaining phenomena scientifically (EP) and content knowledge (CK). This could be explained by their finding that teachers in China tended to spend a large amount of time explaining scientific concepts. The authors further suggest that their findings support the idea that good performance in science "is a result of teaching that is highly content-focused" (Korsnakova et al., 2009; Thomson, 2009 as cited in Lau & Lam, 2017, p. 2144). Wei and Ou (2019)'s finding that the Chinese science curriculum appears to emphasise remembering and understanding over evaluation and other high-level cognitive processes could possibly contribute to the finding that Chinese students demonstrate "weaker knowledge at the high level of cognition…" and "perform less well in activities regarding the ability to evaluate, as suggested by the results in PISA 2015" (Zhang et al., 2017, as cited in Wei & Ou, 2019, p. 1468). However, we must keep in mind that some of this research used data from PISA before the 2018 round, and therefore students may perform differently now.

Summary of key messages

In summary, the review of the literature on China's education, curriculum and science education has shown that:

a) The literature often does not specify if it is referring to all mainland China or specific regions within mainland China. This poses issues when it comes to establishing how representative the findings of the research are to all of China.

b) The initial and in-service teacher training seems to be of high quality, with entrance exams needed to obtain a place on teacher training courses, and the introduction of renewal processes for teaching qualifications for teachers across the education system (OECD, 2016a).

c) Evidence on enquiry-based teaching is mixed. Research suggests that the policy seems to advocate a curriculum that "encourages student-led enquiry and more comprehensive and balanced learning experiences" (OECD, 2016a, p. 38), but studies do not support that this is happening in the classrooms (e.g., Lau & Lam, 2017). Also, the extent to which enquiry is happening in Chinese classrooms is unclear and it may vary widely between classrooms, schools and regions.

d) The literature suggests that the Chinese curriculum recognises the importance of scientific literacy (e.g., Wang et al., 2019).

Macao S.A.R. (China)

General education system

Overview and history

Macao (also known as Macau) is a former colony of Portugal, and its sovereignty was returned to China in 1999 (Wei, 2016). It is considered a Special Administrative Region (SAR) of China and is located west of the Pearl River in southern China (Worldpopulationreview, n.d.). Macao has its own legislation, tax system, police, immigration services, customs, and currency (which are influenced by China) (Worlddata, n.d.). Macao therefore has considerable degree of autonomy under Central government of China.

Stages of education

There was conflicting information from sources about the stages and duration of stages of education in Macao (Gao, 2017; Scholaro n.d.b; Wei et al., 2020). Also, some sources were conflicting within themselves, e.g., Wei et al. (2020) speaks of junior high school and junior secondary schools. In contrast, Scholaro (n.d.b) talks about lower secondary and higher secondary schools. The literature does not provide a clear answer as to when compulsory education starts and ends.

Languages

The main spoken language and language of instruction in Macao is Cantonese. With regards to the spoken language, Cantonese is followed by Mandarin and other Chinese dialects (CIA, n.d.b). Macao's official languages are Standard Chinese and Portuguese (Wheeler, 2019; Worlddata, n.d.). Wei's (2016) study with secondary school students in Macao confirms that Cantonese is the main native language for Macao's students. Wei et al. (2020) writes that there are three types of schools which speak: Chinese, English and Portuguese. Therefore, Macao's languages of instruction (after Cantonese) include Portuguese and also English (The Editors of Encyclopaedia Britannica, n.d.; Wheeler, 2019).

Is education centralised or de-centralised?

During the colonial time, Macao had a "laissez-faire approach to school education" and a de-centralised education system, which saw independent (private) schools "dominating in the schooling system", diversity of school curriculums, no unified requirements for school graduates, and the absence of a standard career and pay structure for teachers" (Tang et al., 2018 as cited in Wei et al., 2020). Since gaining independence from Portugal, Macao's government has exercised greater control over education and attempted to address concerns over the quality of education by developing new regulations and policies, enhancing teachers' professionalisation to promote centralisation (Wei, 2019; Wei et al., 2020) and moving away from models borrowed from Portugal (Lo You Chun, 2005). Despite this, most primary and secondary schools are private and still have great autonomy in planning and enacting the curriculum, selecting materials and teaching methods, and setting standards for examinations and teaching hours. This “school-based teaching syllabus” created by teachers for each subject is the “legitimated curriculum at schools” (Wei, 2016, p. 62). When creating the teaching outlines, science teachers tend to refer to official materials, textbooks and curricula/syllabi from other regions, such as mainland China. School teaching can therefore be said to be heavily influenced by neighbouring jurisdictions (Wei, 2016). Most secondary schools are run by private organisations and follow their own curriculum for natural sciences rather than having to follow the official science curriculum from the Macao government (Wei, 2019). They have the autonomy to decide on the curriculum they adopt and the teaching hours they allocate to each subject. This great diversity across schools' curricula and instruction makes it difficult to make comparisons and draw conclusions about the ‘general’ curriculum.

Despite the attempts to centralise the curriculum, researchers suggest that it is not realistic for the government of Macao to adopt the same forms of curriculum standards or frameworks as other jurisdictions (e.g., mainland China) to unify school curricula across different types of schools. This is because of “the deep-rooted decentralised education system” (p. 3). Wang (2015, cited in Wei et al., 2020) claims that introducing the Requirements of Basic Academic Attainments (RBAAs) (the basic requirements for those completing each educational stage in K-12) was a step towards centralisation.

Curricular reforms and key features of general curriculum

Vong (2014, as cited in Wei et al., 2020) writes that many measures and strategies have been employed to address the quality concerns in education, including new regulations, rules and attempts to centralise the curriculum system in K-12. For instance, in 2006, Macao's government introduced the *Non-Tertiary Education System Law,* which attempted to establish a new K-12 system of education and ensure quality of schooling (Wei, 2019). It also stipulated that the Macao government would be responsible for formulating the RBAAs for subjects in the four educational stages (Wei et al., 2020). The RBAAs refer to the basic competencies that students should have at the end of each stage, including “knowledge, skills, capacities, emotions, attitudes and values” (Wei, 2020, p. 3). Each RBAA contains three sections: “1) *curriculum rationale*”, “2) *curriculum goals*” and “3) *performance requirements*”. In 2009, the Education and Youth Affairs Bureau (or DSEJ – the main educational administration in Macao) established “core competencies” in further attempts to reform the non-tertiary curriculum. The idea of competencies was interpreted into six capacities: “reading and language, using mathematical thinking and methods, using information technology, communication and collaboration, critical thinking and innovation and problem-solving” and three “21st century personal characters” including moral and civic, healthy, and aesthetic (DSEJ, 2009, as cited in Wei et al., 2020, pp. 2-3).

With regards to the key features of the curriculum, Wei et al. (2020) analysed the integration of the 21st century competencies in RBAAs in Macao's curriculum documents, by adopting Binkley et al.'s (2012) framework, which has been used as a tool for curriculum document analysis. Wei and colleagues used Binkley's framework to group ten 21st century competencies into four categories. The ten competencies include:

- creative thinking,

- critical thinking,
- learning to learn,
- collaboration,
- communication,
- information literacy,
- ICT literacy,
- citizenship,
- life and career,
- and personal and social responsibility.

These were then grouped into four categories: *1) ways of thinking, 2) ways of working, 3) tools for working* and *4) living in the world.* The authors then analysed the distribution of the competencies in the curriculum goals of official RBAAs for subjects offered across the four educational stages (pre-primary, primary, junior secondary and senior secondary). Table 5 provides information about the four categories and the ten competencies. For more detail, see Table 1 in Wei et al. (2020) on page 6.

Table 5

The analytical framework for 21st century competencies used by Wei et al. (2020)

Category	Meaning and definition	Competencies
1) Ways of thinking	Includes competencies that focus on the cognitive domain, imaginative competency that involves generating new ideas	Creative thinking Critical thinking Learning to learn
2) Ways of working	Includes competencies that are needed to carry out a project	Collaboration Communication
3) Tools for working	Includes competencies that are needed in comprehending or using “tools”	Information literacy ICT literacy
4) Living in the world	Includes competencies needed to negotiate in the world, related to life, social and cultural responsibilities	Citizenship Life and career Personal and social responsibility

Adapted from Binkley et al., 2012 and Wang et al., 2018 (as cited in Wei et al., 2020)

The authors found that in general, the *ways of thinking* category was seen the most in curriculum documents for primary, junior secondary and senior secondary schools, and *tools for working* was seen the least. *Learning to learn* competency was found to be the most emphasised competency in K-12 (with a frequency of appearance of 48.5% in the RBAAs for primary school, 41.4% in junior secondary school RBAAs and 47.5% in senior secondary school RBAAs) (see Tables 3 and 4 in Wei et al., 2020). *Creative thinking* competency was found to be the least frequently appearing competency across primary, junior and senior secondary RBAAs. Wei et al. (2020) concluded that different 21st century competencies can be found in different learning domains, and this may be linked to the nature of these subjects, for instance, the competency of *communication* was seen more in Language & literature at junior secondary school, and *critical thinking* was mostly occurring in Science & technology (see Table 8 in Wei et al., 2020). For more information about this study and its findings, see Appendix B.

In 2014, the DSEJ issued a regulation titled *Curriculum Framework for Formal Education of Local Education System*, which includes six learning domains: language and literature;

maths; people, society and humanity; science and technology; physical education and health; and arts. Each domain includes various school subjects, for instance, science and technology includes “natural sciences” and “information technology” (Wei et al., 2020, p. 3). The Framework also stipulates a minimum number of teaching hours for junior and senior secondary schools and states that science should be offered to all students, including those in the art streams (Wei, 2019). However, Wei (2019) argues that there are big differences between schools in Macao. For instance, although biology, chemistry and physics are taught at most schools at junior secondary level, the teaching hours spent on each subject differ among schools. Furthermore, diversity of school science curricula is even larger at senior secondary level. In some senior secondary schools where students are split into science and art streams, natural science courses are not offered to those in the art streams.

Textbooks

With regards to textbooks, Wei (2016) states that when teachers create their teaching outlines, they often will consult textbooks from other jurisdictions, such as mainland China. Wei further argues that textbooks have an important role in schools in Macao, but as the market is very small and fragmented (thus commercial publishers do not invest in it), textbooks are often imported from neighbouring areas (Lo, 2004, cited in Wei, 2016). Textbooks from mainland China have the largest share in the market (Wei, 2016). Wei (2016) cites a case study (Wei et al., 2009), which found that chemistry teachers tended to use textbook sequences to decide on teaching hours, content and teaching progress, but they also tended to adapt textbooks based on their teaching experiences. Wei (2016) also indicates that since most textbooks are imported, teachers may sometimes not be aware of changes in the subject, new ideas or pedagogy.

Teacher training and professional development

With respect to teacher training and PD, the review has revealed that teaching is not an attractive career for many, partly because of the large gambling industry in Macao, which offers many job opportunities (Wei, 2019). The Macao government has recognised the importance of teacher development and many measures have been taken to enhance teachers’ professional development and professionalisation. These include financial support and resources offered to reduce teachers’ non-teaching workload and improve working conditions, and more learning opportunities for mid-level management staff to enhance effective school practice for all staff and training offered by the DSEJ to upgrade teaching qualifications and expertise (ibid). Local training programs for primary and pre-primary teachers were initially offered at the University of Eastern Asia (later known as University of Macao). In 1989, the Faculty of Education was established as the first educational department in Macao. Currently, there are six pre-service training programs for teachers. There are also Postgraduate Certificate of Education (PGCE) courses for those who have an undergraduate (bachelor) degree but not a teaching qualification. The DSEJ recognises PGCE courses as a teacher license in Macao. In addition to the University of Macao, two other institutions provide teacher training courses: Institute of Macau Polytechnic (specialising in Arts and Physical Education) and St Joseph University (Cheng, 2018 as cited in Wei, 2019), but neither of those provide science teaching training. The Integrated Science is a new bachelor level teacher training course that has recently opened and is available at the Faculty of Education at the University of Macao. It offers training in integrated areas of science for those wishing to teach at both junior and senior levels.

The University of Macao holds various in-service teacher training programs and projects, such as science teaching workshops on the RBAAs, lectures on advanced science content, which are often supported by the DSEJ. To maintain professional development, the *System Framework for Private School Teaching Staff or Non-tertiary Education* was established in 2012 as a career framework for private school staff. This framework has introduced measures such as promoting professional development, increasing appointment requirements, establishing the career regime and ensuring appropriate pay. For instance, the framework stipulates six scales of teacher's professional rank and states that teachers must complete 30 hours of training to move from a lower to a higher rank (DSEJ, 2012 as cited in Wei, 2019). Teachers may face challenges, including the introduction of integrated science courses, which have started to come into the educational landscape in an attempt to replace individual science courses (Wei, 2019). This requires teachers to have a broader content knowledge that goes beyond their specialised subject, which could pose an issue to some teachers, especially at the early stages of teaching integrated courses. Wei (2016) also writes about other challenges, including that a large proportion of science teachers are young, and a large number have not received any kind of teacher training of education.

The influence of culture on education

In addition to the above, Wei at al. (2020) highlights the importance that culture and society play in any educational system – "as we know, school curriculum development has never occurred in a vacuum and is inextricably linked to historical, cultural, economic and political aspects in a given society" (Kelly, 2009; Marsh & Willis, 2003, as cited in Wei et al., 2020, p. 2). Considering that Macao has been an independent jurisdiction only since the late 1990s, and that the development of a comprehensive curriculum started only in 1989, the literature suggests that it is still shaping its educational system (Lo Yiu Chun, 2005). The state of its educational system, curricula and policies cannot therefore be taken on its own without considering other elements, such as its history, politics or social and economic climate. Wei and Ou (2019) write that Macao is trying to "establish its own educational and curricular systems" (p. 1471).

Science-specific features

Who has contributed to the development of the science curriculum?

As already mentioned, the key groups which have contributed to the development of the national curriculum in Macao include the government and the Education and Youth Affairs Bureau (or the DSEJ – the education administrative authority in Macao). When the *Non-Tertiary Education System Law* was being developed in 2006, the DSEJ started a project aimed at evaluating the current situation in primary and secondary school science education and providing information to the administrative authority and schools "to project the future development of science teaching and to ensure and promote its quality" (EYB, 2007, as cited in Wei, 2016, p. 57). The Bureau commissioned the Faculty of Education at the University of Macau to provide a team for this evaluation. The team included science education specialists, experts in education evaluation and science subject specialists. The project investigated areas including curriculum planning, curriculum organisation and management, teaching quality, science teacher development, learning environment and resources, and parents' expectations (EYB, 2007 as cited in Wei, 2016).

When do students study science and when is science compulsory?

The literature suggests that science is studied in primary schools, junior secondary schools and senior secondary schools (Wei, 2016; Wei, 2019), although at the senior level, students can choose which stream they would like to pursue out of science, art and business. However, Wei (2019) further suggests that not all senior secondary students may learn science, as "science as a subject is not offered for those students in the streams of art and business in some of senior secondary schools in Macau" (p. 7). Wei (2016) found that: whether students chose to study science at senior level (and beyond) depended on interest. The splitting of students into art and science streams was a concern and, at senior level, science was heavily driven by university admission exams.

With regards to the teaching hours, although biology, chemistry and physics are taught in most secondary schools at junior level, the number of teaching hours per subject differs among schools. At senior level this diversity increases, despite the *Curriculum Framework for Formal Education of Local Education System* stipulating the minimum number of teaching hours and that science should be offered to students in the art streams as well as science streams (Wei, 2019). Wei's (2016) study of science teaching and learning in Macao found that at junior level, all participating schools offered biology, chemistry and physics, but less than a quarter offered integrated science, and no school offered earth or space science. The average teaching hours for science for all grades was 13.2 per week, and for each grade it was 4.4 hours per week. At senior level, the average hours of teaching offered for physics and chemistry was higher than for biology. However, they noted that since most schools are private, they have the autonomy to decide on the teaching hours they allocate to subjects.

Influence of research on science education

According to Wei (2019), because Macao is a small jurisdiction, there is not a lot of research interest or empirical data on science education and issues around teaching science in Macao. The research on Macao education is more general and does not address the specific issues found in science curriculum and teaching. The literature did mention that the DSEJ-commissioned a project to evaluate various elements of primary and secondary school science education, with the author acting as the project coordinator in addition to other science, education and evaluation specialists (Wei, 2016). Wei's (2016) paper describes the landscape of science education in Macao from the data collected in this evaluation project (see Appendix B for more information). The literature search revealed that Wei has been a key researcher investigating science education in Macao.

Features and aims of the science curriculum

Wei (2019) specifies that seven curriculum goals have derived from the above curriculum ideas. For the RBAAs in junior secondary schools, these are to:

- "maintain and develop students' curiosity and craving for knowledge about natural phenomena; reinforce their interests in and passion for learning science

- allow students to understand basic scientific knowledge; be able to explain common natural phenomena by using relevant scientific concepts and principles.
- help students master some basic scientific methods and skills; guide them to solve practical problems related to natural science.
- lead students to realize the significance and basic process of scientific inquiry; enhance their experience in and develop their primary ability of scientific inquiry.
- enable students to gradually cultivate such scientific spirit as constant thinking, daring to question, being rigorous in searching for the truth, willing to practice and being good at cooperating with others.
- guide students to comprehend the relationship between science, technology, society and environment; pay attention to science-related social issues to allow them to initially form the awareness of actively participating in the discussion of social issues.
- lead students to understand the nature of science, nurturing their awareness of applying scientific knowledge, methods, and attitude in viewing and solving personal and social issues". (p. 6)

Concerning features of Macao's curriculum, Wei (2016) noted that since many schools are private, they do not need to follow the national curriculum and that teachers often produce their own teaching outlines, suggesting that if there are key features of the curriculum, they may not be followed or enacted in the same way. Wei (2019) suggests that the RBAAs for junior and secondary school contain scientific inquiry (including scientific discovery). The author further states that subject content for junior secondary science was selected from four traditional science subjects (chemistry, biology, physics and physical geography) and that the four learning areas identified for RBAAs for junior schools are: *scientific inquiry, physical science, life science* and *earth and space science.* For senior secondary science, subject content focuses on scenarios where "science demonstrably plays a role in human affairs" (Roberts, 2011 as cited in Wei, 2019, p. 7). Thus, the RBAAs for senior school science include *scientific inquiry, history and nature of science, environments and resources* and *modern technology* (see Table 3 in Wei, 2019 for more information). With regards to the place of scientific inquiry in the curriculum, Wei (2019) suggests that it is present. For instance, scientific inquiry is one of the four learning areas identified for the RBAAs for junior secondary school and for senior secondary schools. It is also a teaching mode in some of the RBAAs. However, Wei claims that scientific inquiry can pose a challenge to some teachers because it includes elements that teachers may not be familiar with. Teachers may therefore need to understand what scientific inquiry really involves and develop their own professional knowledge to deliver it in practice.

Wei et al. (2020) investigated the extent to which 21st century competencies are integrated in the curriculum in Macao. Some findings have already been described above, but with respect to science curriculum, they found that at junior secondary level, the subject Science & Technology was the only domain which included all of the 10 competencies investigated (*creative thinking, critical thinking, learning to learn, collaboration, communication, information literacy, ICT literacy, citizenship, life and career, personal and social responsibility*). Within this domain, *critical thinking* competency was the most occurring one. They summarised their findings as indicating that "at a general level, the category of "ways of thinking" takes most proportion and that of "tools for working" takes the least across educational stages from primary to senior secondary" (p. 12). Secondly, discrepancies exist among how the 21st century competencies are distributed across the phases and seem to conform to physical and psychological characteristics of children at the different phases. Lastly, the domains of Science & Technology, Language & Literature, People, Society & Humanity, and Arts included more competencies than Maths and Physical Education & Health. The authors concluded that how the 21st century competencies are distributed in the different learning domains varies and maybe linked to the nature of subjects.

Furthermore, Wei and Ou (2019) compared the curriculum standards of junior high school science in various jurisdictions, including Macao, using the Revised Bloom's Taxonomy. They found that Macao emphasised conceptual knowledge, followed by procedural knowledge and factual knowledge. Conceptual knowledge had the highest proportion among the four knowledge types in Macao. The interrogated curriculum did not represent meta-cognitive knowledge. The study also looked at the distribution of the six cognitive processes from the Revised Taxonomy (*Remember, Understand, Apply, Analyse, Evaluate* and *Create).* With regards to Macao's junior high school curriculum for science, there was no requirement for *Evaluate*. *Remember* had the largest proportion (46%), followed by *Understand* (37.33%), *Apply* (10%), *Analyse* (4%) and *Create* (2.67%) (see Figure 2 in Wei & Ou, 2019, p. 1468). Wei and Ou (2019) concluded that "in Macao, conceptual knowledge at the *Remember* level is also one of the most essential dimensions, along with conceptual knowledge at the *Understand* level" (p. 1470). Macao also appears to stress conceptual knowledge at the *Remember* level instead of emphasising *Understand* level or higher-level cognitive processes. They suggest that this finding "is not fully compatible with the emphasis on cultivating students' scientific literacy and on explaining phenomena scientifically, as expressed by their curriculum documents and as suggested by the assessment framework of PISA 2015" (p. 1470).

Place of scientific literacy in the curriculum

With regards to the place of scientific literacy, the literature search revealed that the RBAAs include rationale for each subject, curriculum goals and specific content (Wei, 2019). The central goal of the RBAAs for junior and senior secondary schools is scientific literacy. Firstly, as mentioned in the *Non-Tertiary Education System Law*, one of the key aims of pre-college education is to enhance the level of scientific literacy in students (Wei, 2019). The RBAAs have three "basic curriculum ideas" to support the achievement of scientific literacy:

a) "aiming at promoting students' overall development, enabling the improvement of every student's level of scientific literacy,
b) strengthening the connections between different disciplines, helping students understand the relationship between science, technology and society,
c) laying stress on the diversification of teaching methods, and actively promoting inquiry learning" (Wei, 2019, p. 6).

To summarise, scientific literacy was established as a central goal of the RBAAs for both junior and senior schools. Furthermore, the Non-Tertiary Education System Law suggests that increasing the level of scientific literacy of all students is "one of the general goals of pre-college educational enterprise in Macau" (Wei, 2019, p. 5). Wei also states that scientific literacy has been used as a key theme in selecting science curriculum content. This suggests that developing scientific literacy has an important place in the science curriculum.

Opportunities for science learning outside of the classroom

Wei (2019) states that private schools often participate in activities, including encouraging students to take part in science contests and competitions organised by local, national or international organisations. Many of these activities include new technologies such as Artificial Intelligence (AI) or Robotics. Wei (2019) suggests that this can pose a challenge to teachers, as some may not have the knowledge to support students in these areas. However, it is unclear from the literature found to what extent schools that are not private offer the same opportunities.

Science teaching (pedagogy) and how science is experienced in classrooms

The literature review showed that although inquiry seems to be an important element of the curriculum, using inquiry-based teaching methods and promoting inquiry in classrooms may not be as common in Macao as it may seem from the literature. In observations of science classrooms, Wei (2016) found that physics lessons were mostly focused on lecturing, followed by questioning, then teachers' demonstrations, with the least amount of time spent encouraging students to pose questions. Activities were mainly focused on "listening to teachers", followed by "answering questions", "doing exercises" and "observing" (p. 65). Thus, in general, science lessons appeared teacher-dominated, with a passive approach from students and a lack of interactions between students and between students and teachers. Wei (2019) further suggests that textbooks appeared to be used often, but student-centred teaching and strategies were not seen in practice. The classrooms and laboratories did not appear to follow constructivist tenets, with students acting passively, laboratory work was not common, and students did not appear to have many opportunities to give their opinions. Contrastingly, Lau and Lam (2017) found that students in Macao carry out more experiments than the OECD average. Furthermore, Tang et al. (2020) investigated factors predicting inquiry-based teaching in science in various jurisdictions, including Macao. They found that inquiry-based teaching practice was average in Macao, but that certain factors correlated with the use of inquiry teaching. For instance, in Macao, teachers who had science-specific materials at their schools were more likely to adopt inquiry-based teaching more often compared to those who did not. Also, teachers who worked in schools that were located in more developed areas were more likely to adopt inquiry-based teaching approaches.

Student performance in specific components of science in PISA

Finally, with regards to which elements of PISA students perform best in, Lau (2014) analysed the 2012 data and found that Macao's students tended to perform very similarly across all three domains of: *knowledge of science, knowledge about science* and *competency,* although they showed the highest percentage of correct items in the *technology systems* elements found in the *knowledge of science* domain (66.8%) (see Table 3 in Lau, 2014). Furthermore, Lau and Lam (2017) analysed and compared the 2015 PISA data for HPJs and found that students in Macao performed better in areas linked with science contents, such as *explaining phenomena scientifically* (EP) *and content knowledge* (CK) in comparison to other countries such as Korea. However, Macao and other Asian counterparts did not perform as well as Western countries such as Estonia, Finland and Canada in areas related to *Evaluating and designing scientific enquiry* (ED). Wei and Ou

(2019) analysed the distribution of cognitive processes from the Revised Bloom's Taxonomy (2001) in high school curricula in various jurisdictions, including Macao. They found that the science curriculum documents from Macao emphasised conceptual knowledge, followed by procedural knowledge and factual knowledge, and that lower order thinking skills, such as remembering, and understanding were also emphasised more than higher lever skills such as evaluation. This is similar to findings from mainland China, where conceptual knowledge also had the highest proportion in curriculum documents. Lastly, meta-cognitive knowledge was not present in the curriculum documents of Macao and mainland China. It is worth mentioning that the PISA assessment may have changed slightly since the 2012 and 2015 rounds, and the items that were assessed in the studies above may not be the same as the ones found in the latest 2018 round. However, it is beyond the scope of this review to compare the items in each round of the PISA assessment.

Singapore

General education system

Singapore places huge importance on education and people development, as education is seen as a key contributor to building the workforce (Tan et al., 2016).

Stages of education

The following stages exist in the Singaporean education system:

- pre-school (for children aged 3-6 years old)- including public or private kindergartens or childcare centres, which is not compulsory,
- primary school (starting at age 7 until 12 years old or grades 1-6) and is compulsory (Lee, 2018), with the first 4 years being a foundation period and the last two years being an 'orientation' period to prepare students for secondary school. The curriculum is common for all students in years 1-4 (NCEE, n.d.c),
- secondary school (starting at 12 years old until 16/17 years old or grades 7-10) and is compulsory,
- post-secondary – could include university preparation or vocational training (starting after secondary school and lasting 2 or 3 years) but is not compulsory and is aimed at students who wish to study at university (NCEE, n.d.c; Wise, 2017).

Languages

English and bilingualism are seen as incredibly valuable and English tends to be the main language of instruction (Tan et al., 2016; Wise, 2017) but students will also study their mother tongue (Wise, 2017) and tend to use this at home (Tan et al., 2016). English tends to be spoken by a large proportion of the population and is considered an official language of Singapore, followed by Mandarin (also official language) and other Chinese dialects (CIA, n.d.c).

Is education centralised or de-centralised?

According to NCEE (n.d.c), the education system in Singapore is heavily centralised, with the Ministry of Education overseeing most aspects related to education, such as funding, setting of course syllabi and examinations, teacher recruitment and accreditation and many more. Schools are also placed into clusters overseen by superintendents (successful former principals) who collaborate with other principals on the best way to implement the curriculum, which teaching methods to use from the Ministry's approved set, and about sharing of materials and best practices (NCEE, n.d.c). The Ministry of Education has been heavily involved in implementing its primary and secondary curricula, with officials having "hands on" roles in schools, meeting with school leaders and developing professional development opportunities for teachers. However, the NCEE (n.d.c) also reports that in recent years the Ministry has "taken a step back" to encourage schools to "consider the curriculum as a framework which they should adapt to their students' needs" (Standards and Curriculum, para 4). According to the NCEE (n.d.c), the Ministry also encourages schools to differentiate themselves through various themed courses and special programmes for students with shared interest.

Who oversees the curriculum?

The Ministry of Education sets course syllabi and national examinations. Although the Ministry sets the educational system's framework, other bodies operate within this set framework, including the National Institute of Education (for teacher training), the Examinations and Assessment Board (for national examinations), and the Institute of Technical Education (for vocational education) – all of which work very closely with the Ministry (NCEE, n.d.c).

Curricular reforms and key features of general education system and curriculum

A free universal primary education was achieved in the late 1970s. In 1980, a two-tier curriculum was established (requiring students to study both English and mother language) and three-stream system was established at primary school level, which tracked students into three streams: *normal bilingual, extended bilingual* and *monolingual*, based on performance in examinations at the end of Primary 3 (Deng & Gopinathan, 2016). The words 'stream' and 'track' appear to be used interchangeably in the literature. Additionally, the two-tier curriculum seems to refer to the bilingual education policy whereby all students tend to learn curriculum content through English but are also required to study a second language (their official mother tongue) and to reach proficiency in it (Dixon, 2005). Lee and Phua (2020) state that the Goh Report introduced streaming in 1979. According to this report, streaming aims to separate students based on their academic abilities and to use different curricular approaches with each stream. According to Lee and Phua (2020), about 60% of primary school students will be placed into the *normal bilingual* stream at Primary 1, where they will study two languages: English and one mother tongue and take the Primary School Leaving Examination (PSLE) at the end of Primary 6, thus will complete their primary schooling in six years. About 20% will be placed in the *Extended bilingual* stream, where they will study two languages (English and one other mother tongue) but will take then PSLE examination at the end of Primary 8, thus will complete their primary education in an extended period of eight years. The other 20% will be placed in the *Monolingual stream*, where they will focus on learning one language and basic numeracy, and may be prepared for vocational training (Gopinathan & Mardiana, 2013; Tan et al., 2008 as cited in Deng & Gopinathan, 2016). Lee and Phua (2020) cite the Goh Report to explain why many Chinese students may find themselves in the Monolingual stream. According to them, English is linguistically different to the mother languages spoken at home (such as Mandarin) and for students who may be below average, and do not have the support for English at home, they may struggle to learn two different languages. This may be why they are taught one language that is more similar to the language spoken at home.

Three similar streams were also set up for secondary education: *Special, Express* and *Normal* although it appears that the *Normal* stream is split into *Normal* (academic) and *Normal* (technical) (Impel, 2019; NCEE, n.d.c). The NCEE suggests that all streams offer the same courses, but the Express stream is “accelerated” and the Normal (technical) is more applied. Other sources state that in 2014, subject-based banding was prototyped for secondary schools in Singapore and was rolled out in 2018. According to the Ministry of Education (2019), secondary school students in the Normal (academic) and Normal (technical) streams could take subjects such as English, mother tongue language, maths and science at a more advanced level. This subject-based banding would allow secondary students to take certain subjects at the Express level if they obtained a high enough result for that subject in the PSLE and if they perform well in a school-based assessment after starting secondary school (Secondary 1). Students may also transfer to the Express course at the end of Secondary 1 and 2 based on their performance and teacher assessment (Ministry of Education, n.d.).

In 1980, the Curriculum Development Institute of Singapore was established to develop syllabi, guides and textbooks for all schools in order to standardise the curriculum (Deng & Gopinathan, 2016). In 2019, the Singaporean government dropped examinations for students in Primary 1 and 2 and in 2021 dropped mid-year exams for students in Primary 3 and 5, as well as Secondary 3 (NCEE, n.d.c).

With regards to the key aims of the curriculum, Deng and Gopinathan (2016) suggest that the present education system has come about as a result of the transformation that Singapore has undergone to a “modern industrial nation with political stability and economic prosperity over one generation” and that education is a “means for social cohesion, a vehicle for economic development, and a platform for nation building” (Gopinathan & Mardiana, 2013 as cited in Deng & Gopinathan, 2016, p. 16). Deng and Gopinathan (2016) also suggest that the national curriculum emphasises “the development of students’ competences in mathematics, science, and languages – the three subjects tested in PISA… a commitment to academic rigour and standards, underpinned by the principle of meritocracy and enforced by a system of national high-stakes examinations (PSLE, ‘O’ and ‘A’ Levels)… This is a system that ensures effort on the part of students and teachers and a system-wide emphasis on academic performance, and rewards following outstanding performance” (p. 16).

With regards to the key features of the curriculum in Singapore, between 1959-1978, the education system went through a survival-driven phase, which focused on developing a literate and technically trained workforce in order to ensure Singapore’s economic survival (Goh & Gopinathan, 2008, Ministry of Education Singapore, 2010, as cited in Tan et al., 2016). Between 1997 – 2011, the curriculum went through an ability-driven phase, which increased flexibility and variety in the school system, and the curriculum was reduced in order to make space for inquiry activities (OECD, 2016b). Teachers were encouraged to collaborate in lesson planning and to conduct active lessons, there was an investment in information and communication technology (ICT) and more autonomy was given to schools

(Poon et al., 2016 as cited in OECD, 2016b). Since 2012, the curriculum has undergone a student-centric, values driven phase, which sees continuous drive towards inquiry and application of knowledge to solve problems (Tan et al., 2016) and which saw the development of the *21st Century Competencies and Student Outcomes* framework – a framework that states "the core competencies and values that will enable the youth of Singapore to thrive in the 21st century" (the 21CC, MOE, 2014 as cited in OECD, 2016b, p. 2). This framework guided the development of syllabi and materials: schools use the framework to develop curricular and co-curricular programmes in order to support students in developing the competencies (OECD, 2016b). The 21CC framework includes the following "core values" or competencies:

- confident person, self-directed learner, active contributor, concerned citizen,
- communication, collaboration and information skills, civic literacy, global awareness and cross-cultural skills, critical and inventive thinking,
- self-awareness, self-management, social awareness, relationship management and responsible decision-making (see Figure 1 in OECD, 2016b).

Textbooks, resources and the use of technology in education

Teachers depend heavily on textbooks and instructional materials, and textbooks are seen by teachers as containing factual information from the national curriculum, which students are then tested on (Deng & Gopinathan, 2016).

With regards to technology, Singapore's Student Learning Space (SLS) is a Ministry-curated library of curriculum-aligned resources such as lesson plans, assessments and videos for all subjects and grades (NCEE, n.d.c). These are consistently updated following teacher and student feedback. The SLS was piloted in 2017 and expanded to schools in 2018, with every student in grades 1-12 being able to access these online materials. Teachers can choose to share their lessons with other teachers on the SLS and students can access SLS resources on the platform. Since the 2020 pandemic, Singapore made home-based learning via SLS a permanent element of the education system, starting in 2021 for secondary students, who will have up to 2 days a month of online learning. All secondary students will also be offered devices. The NCEE says there are plans to pilot online learning for primary school students (n.d.c). According to Lee (2018), every primary school is equipped with curriculum materials such as teacher guides, which are provided by the Ministry of Education. The teaching guide is a comprehensive resource containing lesson plans, activities, assessment tasks and online resources.

Teacher training and professional development

In addition, teacher training and professional development in Singapore are mentioned consistently in the literature. In Singapore, teachers must have at least a bachelor's degree (Tonga et al., 2019). Lee (2018) writes that almost every teacher in Singapore trains at the National Institute of Education (NIE), where students on the undergraduate course must spend four years, with opportunities for field experiences in schools and community service projects. Few primary teachers have a background in science, with the majority of science graduates studying to teach at secondary level or above. Tonga et al. (2019) found a commonality between many HPJs such as Singapore, China, Japan and Estonia in terms of their pre-service teacher education. They found that pre-service teachers in these HPJs learn about pedagogical and content knowledge, and skills needed for inquiry, methodology, communication, ICT studies and other languages, which means that students are often taught by teachers with a very wide skill set. Applicants to secondary school teaching courses must have an undergraduate (bachelor's) degree and can sit the *Qualification Entrance Exam* to be admitted to study Post-Graduate Competency in Education, which is devised for secondary teaching candidates and lasts for 2-4 years. Singapore has different requirements for entry to the teaching profession for primary and secondary school teachers. Furthermore, there is a quota system used to determine the number of candidates that become accepted on to teacher training courses, but teacher trainees do not need to sit additional examinations after completing their course and before entering the classroom (unlike in other HPJs). The Ministry of Education offers scholarships and salaries to pre-service teachers across teaching programmes (Tonga et al., 2019).

With regards to teacher training and development, teachers in Singapore receive in-service training, as courses are offered by many institutions such as the NIE, which often collaborates with the Ministry of Education. Teachers can continue their education by studying for Master and doctoral degrees and can also receive grants and salaries for taking up studies at this level (Zuljan & Vogrinc, NIE, 2013 as cited in Tonga et al., 2019). Lee (2018) notes how previous researchers have suggested that high national performance in TIMSS could be an outcome of the teacher training in Singapore, possibly partly because there is an "emphasis … on pragmatic and instructional issues rather than social and equity issues… less on the analysis of theoretical constructs and more on the application of concepts and practices" (e.g., Wong et al., 1998 as cited in Lee, 2018, p. 191). Wong et al. (1998) also suggests that there is a close fit between teacher training and school practice, which could mean that early career teachers are prepared for teaching adequately (cited in Lee, 2018).

Teachers in Singapore also actively participate in further professional development (PD) opportunities, and Lee (2018) reports that their participation exceeds the OECD average. As not many primary teachers are science specialists, the Ministry is beginning to employ specialist teachers. The NIE also offers PD courses, formal certifications and training, in addition to the PD opportunities offered by the Ministry, the Academy of Singapore Teachers (AST) and school collaborations (Lee, 2018). Some ad-hoc, short courses by the NIE include STEM education, discourse studies in science, scientific argumentation and topics in the natural sciences and problem-based learning (Lee, 2018). The AST (which is run by the Ministry of Education) also offers a subject chapter in primary science, which is led by Master Teachers, who are experts in classroom pedagogy (Lee, 2018). Singaporean teachers can choose one of three tracks in their career: a teaching track, a leadership track or a specialist track. The teaching track (which contains Master teacher level) is designed for those who want to become expert teachers, stay in the classroom, mentor colleagues and develop their expertise in pedagogy. Master teachers mentor other teachers, drive new pedagogies to improve school-wide practice, promote their subject and lead curriculum innovation. There were only about 70 Master teachers out of 33,000 in Singapore (National Institute for School Leadership, 2019). Teachers become Master teachers over years of experience, research and training (Crehan, 2016). Furthermore, science teachers can attend science education conferences, including the International Science Education Conference which occurs at the NIE every three years, as well as the Singapore International Science

Teachers Conference (AST). Tan et al. (2016) suggests that during teacher training and PD courses, teachers are encouraged to take caution and care when teaching models (the theme “Models”, which is usually taught in secondary schools), as students may need time to understand various models and make sense of those. The author also writes that some secondary and pre-university schools have teachers with Master’s and Doctoral degrees in science.

The influence of culture on education

It is important to note that Singapore’s current education system is a blend of many historical, social, political and institutional factors (Deng & Gopinathan, 2016). For instance, Deng and Gopinathan (2016) write about the development of the Singaporean education system in the post-colonial time (1956 - 1987). They mention the political, economic, social and educational challenges that the jurisdiction faced, as well as the recognition of the importance of English, and how this has contributed to socio-economic modernisation. They also comment on the introduction of civics and citizenship into the curriculum and education to help students understand nation building, encourage civic responsibilities, and teach them to “appreciate the desirable elements of both Eastern and Western traditions” (Baildon & Sim, 2010; Tan, 2010 as cited in Deng & Gopinathan, 2016, pp. 12-14).

Another example of a cultural factor involved in education is that private tuition is common for key school subjects and is often taken up due to the pressure to do well in school and in high-stakes examinations at the end of primary school (the Primary School Leaving Examination or PSLE) (Lee, 2018). This shows that the education system of one jurisdiction is a lot more complex than can be presented in a single paper. This report focuses on the last decade of educational developments, but many earlier events, curriculum reforms and historical developments would have contributed to the current state of its education.

Science-specific features

When do students study science and when is science compulsory?

Science, although valued, is delayed until grade 3 in primary school (age 9) to allow the learning of two languages and mathematics in earlier years. The primary science curriculum is revised every six years (Lee, 2018). In grades 3-4, learners receive 90 minutes of science instruction per week, and over 150 minutes in grades 5-6 (ibid). In lower secondary schools (grades 7-8), all students study science (Tan et al., 2016). This is a more integrated science syllabus aimed at developing their scientific literacy, which builds on what they studied in primary school[3]. At lower secondary level, students may spend about 3-3.5 hours studying science each week. The time allocated to one science subject varies from 3-4 hours a week in upper secondary school. At upper secondary school level (15-17 years old), science is an elective subject, although most students choose to study at least one science subject, and some choose combined sciences, e.g., chemistry-physics. At the end of secondary education, students take a national exam – the Singapore-Cambridge General Certificate of Education (Ordinary Level) Examinations. After upper secondary school, some student may

[3] For an overview of the 2013 lower secondary science syllabus, please see Table 9.2 in Tan et al. (2016) on page 163.

attend pre-university education at 17-20 years of age, during which science subjects can be chosen as major subjects (Higher 2 level or H2) in the Singapore-Cambridge General Certificate of Education (Advanced Level) examinations. Students can however choose to study science as minor subject (H1). At this level, students study science for about 5 hours a week (Tan et al., 2016).

Influence of research on science education

Although the literature searching has revealed fewer articles for Singapore compared to China, the research information available appears more coherent and easier to interpret. Tan (2010) conducted a review of research into science education in Singapore between 1971-2008 and concluded that studies conducted before 1990 focused mostly on local issues and were usually not published in international journals (as cited in Tan et al., 2016). She suggested that science education research started to grow after certain policies came into place, such as the use of ICT in schools and the policy of developing students' thinking and creativity skills. Furthermore, in 2004, the Centre of Research in Pedagogy and Practice was established, which contributed to the progress of science education research. Tan et al. (2016) suggests that

> "while studies elsewhere have suggested that research appears to have limited influence on classroom practice and policy (e.g., Davies & Nutley, 2008 as cited in Tan et al., 2016), studies have yet to be conducted to determine how the uniquely close relationship between the National Institute of Education, the Ministry of Education and schools influence the impact of science education research on classroom practices". (pp. 168-169)

Features and aims of the science curriculum

The latest iteration of the curriculum occurred in 2014 and *inquiry* was adopted as the defining characteristic of the science curriculum (Lee, 2018)[4]. The main goals of primary science are to:

- provide students with experiences that stimulate their curiosity,
- provide students with basic scientific terms and concepts,
- provide opportunities to develop skills, habits of mind and attitudes needed for scientific inquiry,
- prepare students to use scientific knowledge and methods,
- help learners appreciate how science influences people and the environment (CPDD, 2013, as cited in Lee, 2018).

The aims of science subjects in upper secondary school (and pre-university education) are to give students the scientific knowledge, skills and attitudes to "become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific importance" (Singapore Examinations and Assessment Board, 2013a, b as cited in Tan et al., 2016, p. 166).

Tan et al. (2016) state that later phases of primary education see subject-based "banding" (setting). Considering the key features of the science curriculum, Tan et al. (2016) propose

[4] For an overview of the 2014 primary science syllabus, please see Table 9.1 in Tan et al. (2016) on page 160.

that the last two curriculum review cycles have emphasised the development of “themes and big ideas across the spiral curriculum” (p. 169). The primary science curriculum has been suggested to have “adopted inquiry as *the* defining feature of the curriculum (CPDD, 2014 as cited in Lee, 2018, p. 187). While the teacher is the leader of inquiry, the student is regarded as the key inquirer who raises questions about science in daily life, in his/her environment, and in society” (Lee, 2018, p. 187). Additionally, Lee suggests that the curriculum also focuses on scientific content (knowledge), its application, scientific skills and processes, as well as ethics and attitudes to science. Furthermore, other important aspects are the 21st century competencies and achieving scientific literacy, where being literate is considered as “being able to reason from evidence and apply knowledge in real world contexts”, which is a reflection of a more “contemporary version of what it means to be educated in science” (p. 187). Tan et al. (2016) further suggests that the Singapore curriculum adopts a spiral design, so that many of the primary science topics are re-visited in the lower secondary science curriculum. The lower secondary curriculum, similarly to the primary, is also focused on inquiry as its key feature, which guides teachers and students in exploring big ideas and important concepts in themes (Ministry of Education Singapore, 2012c as cited in Tan et al., 2016). Teachers are also encouraged to make connections between concepts in the different themes and reduce students separating knowledge. The lower secondary science syllabus has also adopted a new strand called the Scientific Endeavour, which includes the topics of “scientific inquiry” and “science and technology in society”. This strand is not taught as an independent topic but is also integrated into the teaching of other topics. At primary level, the content is organised into five integrated themes: diversity, interactions, systems, cycles and energy (Lee, 2018). At lower secondary level, one additional theme (“models”) is added, and science continues to be taught as a “way of exploring the physical and natural world” (OECD, 2016b, p. 4). Lee (2018) agrees that this thematic approach and the aim of developing scientific literacy through inquiry learning continues in lower secondary schools (grades 7 and 8), but he proposes that most of the learning objectives in the cognitive domain would be placed “on the lower levels of knowledge and cognitive processes in Bloom’s revised taxonomy” (Anderson & Krathwohl, 2001), which raises the issue of whether the curriculum could indeed develop deep, critical thinking in science (Lee et al., 2015 as cited in Lee, 2018, p. 188).

With regards to the curriculum, more concepts in chemistry are introduced in the lower secondary syllabus compared to primary (Tan et al., 2016). As Singapore adopts the spiral curriculum model, topics covered in primary school are re-visited and developed further in lower secondary science lessons. Students learn more about the practice of science, nature, the connections between science and technology, society and environment. It also appears that students in lower secondary science learn more about the theme of “systems”, including various transport systems in plants and animals and advanced topics about the human digestive system (such as the functions of enzymes), which would be considered to fall into biology broadly speaking. Social and moral issues are also considered (ibid). At upper secondary and pre-university level, inquiry activities are not as common as in primary and lower secondary levels. More focus is given to preparing students for higher education and thus time is often spent on preparing for national examinations (Tan et al., 2016). OECD (2016b) proposes that the Singapore Science Curriculum Framework focuses on “the spirit of scientific enquiry and is based on the three domains essential to the practice of science: knowledge, understanding and application; skills and processes; and ethics and attitudes”

(MOE, 2012; MOE, 2013 as cited in OECD, 2016b, p. 4) (for more information on the literature examined please see Appendix C).

Place of scientific literacy in the curriculum

The literature suggests that scientific literacy has an important place in the Singaporean science curriculum, especially as developing scientific literacy is seen as being part of the twenty-first century competencies framework adopted by the Ministry of Education in order to prepare students for globalisation and technology (MOE, 2010c, as cited in Tan et al., 2016).

Opportunities for science learning outside of the classroom

In addition to the science content communicated in the curriculum, the literature suggests that students in Singapore have opportunities to experience “a wide range of enrichment programmes” that may “complement the formal curriculum” (OECD, 2016b, p. 5). This includes science fairs, competitions, learning trials, camps, workshops, and events from research institutes. The Ministry of Education also works with various organisations such as the Agency for Science, Technology and Research (A*STAR) and the Singapore Science Centre in order to design programmes for students. Some of the events include the A*STAR Talent Search (a competition of science projects, aimed at 15–21-year-olds who are mentored by an academic from an A*STAR institution or university), CRADLΣ (where a group of scientists, support staff and educators support hands-on inventions by lending equipment to schools, holding workshops for secondary school students with the aim to see the applications of science). Another programme designed for those with an interest in science is the International Science Drama Competition, which enables students to use drama to communicate scientific content, originally aimed at primary students, but now open to the public (OECD, 2016b). Lee (2018) notes that the Singapore Science Centre has been “a major institution devoted to the promotion of interest and knowledge of science for the past forty years” (p. 190), with nearly all school-aged children visiting it at least once. The Centre puts on a wide range of science activities for children and adults, encourages subscription to science magazines and participation in science fairs/competitions at differing levels (schools, national). It also offers informal science learning to students in primary schools.

Science teaching (pedagogy) and how science is experienced in classrooms

This review has also brought attention to the elements of teaching/learning approaches and pedagogies observed in Singapore science classrooms. Tan et al. (2016) suggests that field trips are common to teach specific topics such as biodiversity. The key mention across the literature has been inquiry-based learning, which is seen as being at the centre of instruction in primary science classrooms (Lee, 2018). Lee (2018) also cites a 2017 study by Kwek et al., which investigated the everyday classroom practices of grade 5 science teachers in Singapore. This study found that the majority of observed classroom talk was factual, followed by exploratory and procedural talk. The knowledge focus of talk was mostly factual, followed by conceptual and procedural, whilst discussions around epistemic and meta-cognitive knowledge were not common. They also found that questions posed by teachers were mostly closed and that classrooms were dominated by teachers talking, students listening to the teachers, answering questions and making notes. However, they also found that teachers who emphasised conceptual development showed teacher-directed inquiry. Teachers felt that developing an interest in science and linking science to everyday life is important. Lastly, they found that teachers perceived examination technique as critical to helping students move to the next level. Deng and Gopinathan (2016) write about a distinct kind of pedagogy in Singaporean classrooms, which they called 'instructional regime' or 'pedagogical regime' and identified three specific characteristics of this pedagogy:

- classroom teaching being mostly focused and driven by covering content and preparing students for high stake exams,
- teachers relying on whole class lectures and questioning as the dominant methods, along with heavy dependence on textbooks, worksheets, homework and focus on students mastering specific procedures and problem-solving skills,
- teachers not using constructivist pedagogical methods (e.g., monitoring understanding, checking prior knowledge, providing formative feedback), and if constructivist pedagogies are used, they tend to be used so students know the correct answer rather than develop conceptual and higher order skills. This also encompasses classroom talk being mostly dominated by teachers and used to check if content has been mastered (Hogan et al., 2013; Hogan, 2014; Vaish, 2008 as cited in Deng & Gopinathan, 2016).

Hogan et al. (2013 as cited in Deng & Gopinathan, 2016) propose that research into classroom practice in Singapore demonstrates a 'hybrid pedagogy' – with a focus on direct instruction and traditional pedagogical practices, and a weaker focus on constructivist learning elements. They suggest that this pedagogy could explain some proportion of the success of Singaporean students in PISA (and TIMSS). Lau and Lamb (2017) found that science classrooms in Singapore see a good proportion of teacher-directed teaching, and adaptive instruction. Adaptive instruction refers to teaching that is mostly teacher-led but is also adapted to students' needs. More students in Singapore also reported that they receive individual feedback from teachers compared to other HPJs. They also found that explaining scientific ideas by the teacher was more common than the OECD average in Singapore, which in turn means that teaching can be quite one-way (didactic). Whole-class discussion was found to be common, which supports Deng and Gopinathan (2016), but it can be more authoritative than dialogic (Mortimer & Scott, 2003 as cited in Lau & Lam, 2017). Furthermore, students in Singapore tended to do more experiments than the OECD average and had more opportunities to express ideas in classrooms. Lau and Lam (2017) concluded that "in general, … and Singapore tend to be more student- and enquiry-oriented in science teaching, whilst Japan and Korea more traditional and didactic" (p. 2144), which slightly challenges research, which claims that a more didactic, teacher-led style is still common (e.g., Deng & Gopinathan, 2016). It also highlights a contentious issue, which will be explored in the discussion section – namely to what extent the research is consistent in suggesting that inquiry learning/teaching is common in these five HPJs.

Student performance in specific components of science in PISA

With regards to Singapore's performance on specific areas of science in the 2012 PISA, Lau (2014)'s analysis showed that Singapore performed above the OECD average on *knowledge of science, knowledge about science* and *competency*. Lau (2017) analysed the 2015 science PISA data and showed that Singapore performed the best in all areas (*explaining phenomena scientifically, evaluate and design scientific enquiry, interpret data and evidence scientifically, content knowledge* and *procedural and epistemic knowledge*. In an analysis of the 2015 science data from PISA, Lau and Lam (2017) found that Singapore has the highest proportion of top performing students, but also a small proportion of low performing students, indicating that "its science education can cater for the needs of both the academically strong and weak students" (p. 2135).

Japan

General education system

Stages of education

In Japan, the following stages of education exist: preschool, primary (also known as elementary) and secondary education (split into junior high school/lower secondary school and senior high school/upper secondary school). Children can attend two types of pre-school education: childcare centres (usually full day and aimed at children from birth to 6 years old) and kindergartens (usually half day and serve children from 3-6 years old). Compulsory schooling starts at primary (elementary) school and lasts for six years at this level (6/7 years old – 12/13 years old) and is followed by three years of lower secondary school (12/13 years old – 15/16 years old). Most students who complete lower secondary school continue to either private or public upper secondary schools. This happens at around the ages of 15/16 – 18 years old. Some students may choose to study at vocational school instead of the more academic upper secondary school. There are several vocational schooling options, including specialised vocational high schools, colleges of technology and training courses. Some schools offer integrated academic and vocational coursework (NCEE, n.d.b; Jnto, n.d.).

Mariel et al. (2021) writes that the Japanese comprehensive school system is very competitive and compulsory in the first two phases: elementary school and lower secondary school. Afterwards, students can choose to continue with upper secondary school or in colleges of technology. Upper secondary school is either academic or vocational. The majority of secondary schools in Japan do not include both lower and upper secondary stages, therefore students often need to change schools. There is a small but increasing number of schools that combine both lower and upper secondary levels, so students do not need to apply to upper schools (NCEE, n.d.b). According to the NCEE (n.d.b) until 2002, students in primary and secondary schools attended school for six days a week (including Saturdays). In 2013, the Ministry allowed schools to bring back Saturday schools if they wanted to. In order to gain admission into upper secondary schools, students complete compulsory entrance exams, which determine if they go to lower or higher-prestige schools. There is a type of hierarchical ranking system, where schools are ranked by the minimum exam scores needed for admission. However, in recent years, the admission process has been undergoing some changes, such as the option to take more than one entrance examination in the same year.

Neither public nor private upper secondary schools appear to be completely free, but public schools have been reported to be cheaper than private schools. In 2010, the government made public upper secondary schools tuition-free in order to support poorer families and to enable all students to attend upper secondary school irrespective of their financial situation (Mariel et al., 2021). However, it is unclear if public schools are now completely free or if they still carry some (very low) general fees, and the literature does not clarify this completely. A document written by Abumiya (2012; who appears to be a researcher in Japan) states that a standard tuition fee for public high school was around 118,800 Japanese Yen per year (equivalent to around £725.30). The report also states that the difference between the standard and actual school fees will be taken from students' households. However, further investigations did not find other sources which confirmed these figures, therefore this should be taken with caution. Additionally, at the same time the government introduced a subsidy for those attending private schools (equivalent to the tuition fee cost at public schools). Since 2014, an income limit has been introduced to check families' eligibility to receive this subsidy and changes are consistently being made to this system (Mariel et al., 2021).

Languages

The main language spoken in Japan is Japanese and it is also the language of instruction in Japanese schools. However, in some areas (such as those with a large proportion of Brazilian communities), education may be offered in Japanese and Portuguese (Ginshima & Matsubara, n.d.).

Is education centralised or de-centralised?

Kumano (2009) states that one of the reasons for Japan's economic and national success is that Japanese people believed they were part of the process of developing a "well-organized centralized education system" (p. 2). The NCEE (n.d.b) suggests that although teachers can make changes to the curriculum, they are expected to follow it, indicating that the education system is centralised.

Curricular reforms, key features and aims of the general curriculum

A 1998 reform saw a drive to "develop education that helped children securely acquire the "absolute value at all stages"" (Kumano, 2009, p. 3) – values that all students should learn in Japan. To achieve this, a new subject called *Period for Integrated Study* was introduced into the national curriculum in 2002 and about 30% of hours dedicated to other subjects were reduced to include this subject. This Integrated Studies (IS) programme attempted to increase teacher autonomy and increase students' interest in learning (Bjork, 2009). The IS programme was seen as a way of investigating issues that children may face in everyday life. Curriculum developers concluded that schools could set their own school-wide and grade-level themes for the IS programme (e.g., social welfare, environmental issues, local industries etc.). Schools were given the freedom to decide on the hours they spend on learning activities for the IS programme, the subjects covered and content at each grade in an attempt to allow teachers to "create the curriculum by themselves, producing their own original ideas" (Bjork, 2009, p. 24). Japan's National Course of Study (CS) identifies what schools should cover across grades and is amended every 8-10 years (Kumano, 2009), with new curriculum being rolled out in stages (NCEE, n.d.b). Lau (2014) suggests that Japan started a "relaxed education" in 2002, which focused on creative thinking, but this was later changed to pay more attention to basic knowledge and "Zest for living" (p. 16). The national curriculum standards were revised in 2008-2009 and enforced in 2011- 2012/13. The 2013 reform brought in more instructional time and increased content and rigour of subject matter (NCEE, n.d.b).

With regards to the key features of curriculum, the 2013 revision of the curriculum intends to "further develop cross-curricular competencies such as problem-solving, creativity, and good learning habits by emphasizing active learning in all courses" (NCEE, n.d.b, Standards and Curriculum, para 3). The curriculum is organised into three themes: "*motivation to learn and apply learning to life, acquisition of knowledge and technical skills,* and *skills to think, make judgements, and express oneself*". It makes informal English instruction start as early as in the third grade, introduced coding as a required subject in the fifth grade and adds coursework in scientific exploration and geography (NCEE, n.d.b). Most recent revisions to the curriculum standards were announced in 2017 for elementary and lower secondary schools (enforced in 2020 and 2021 respectively), and revisions for upper secondary schools announced for 2018 with enforcement of these to occur in schools in 2022 (Nakamichi & Katayama, 2018) (though it is not clear whether the impact of COVID-19 prevented these revisions from occurring).

Japan's primary school curriculum is split into three main categories:

- compulsory subjects (Japanese language, Japanese literature, mathematics, social studies, science, music, arts and handicrafts, and physical education. English is required in fifth and sixth grade but is usually taught through informal activities),
- moral education (aims to teach students respect of others and the environment, rules of society and general self-control), and
- special activities (activities that highlight teamwork and co-operation, such as field trips or school concerts).

Computer programming was added into the primary curriculum as a compulsory subject in 2020. In lower secondary school, the same compulsory subjects continue, and fine arts and foreign languages are added in (e.g., English, French, German). At upper secondary curriculum, the compulsory subjects continue, but the curriculum also includes science inquiry and social science inquiry courses. Computer programming is set to be added to the upper school curriculum in 2022 (NCEE, n.d.b).

Textbooks, resources and the use of technology in education

Textbooks produced by publishers adhere very closely to the national curriculum and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) examines and approves textbooks before they are available for schools to be used. Local boards of education select which Ministry-approved texts are used in schools. Ministry specialists also prepare guidebooks for teachers in each subject, with support from experienced teachers (NCEE, n.d.b).

The NCEE (n.d.b) writes that overall, Japan's education system "has been slow to adopt digital technology and online learning" (Digital Platforms and Resources, para 1). The COVID-pandemic has sped up the plans for online learning in schools and the MEXT has developed the *Education in Japan Beyond the Pandemic* plan, which aims to provide each student with a device, as well as equipment so that children can work from home. It also aims to build an ICT structure in schools, including online learning systems and education data collection systems. The MEXT has also developed a platform which hosts online learning materials (Children's Learning Support Website).

Equality in education

With regards to equality and access to education, the NCEE (n.d.b) states that since the Second World War, Japan has promoted access to opportunities as a "function of effort and merit determined by school achievement" (Context, para 2). Primary education was offered universally at the start of the 20th century, and after the Second Would War, compulsory schooling was extended to nine years (six years at primary and three at secondary school). Japan attempts to equalise funding for schools by paying centrally for teachers and expenses. There is no tracking throughout compulsory schooling. These policies may have contributed to providing students from lower social-economic backgrounds "relatively equal opportunities" (NCEE, n.d.b, Context para 2), which could be supported by the finding that in the 2018 PISA, only 8% of variation in student reading performance was attributed to socio-economic backgrounds (which is lower than the OECD average of 13%). However, the belief that achievement is gained through hard work and the practice of testing for admissions into secondary schools and higher education have contributed to a culture of after-school tutoring. The NCEE (n.d.b) states that tutoring schools in Japan (known as *juku*) are attended by over half of all Japanese students. Furthermore, it appears that the government has attempted to help poorer families gain access to private schools by offering a subsidy. It is still unclear if public schools are completely-tuition free, or if they carry some financial cost. This poses questions around equity and access to education.

Teacher training and professional development

Isozaki (2018) states that pre-service teacher education has placed more emphasis on professional studies and less on research theories that can support teaching and learning of science.

Teachers in Japan are believed to work some of the longest hours compared to other OECD jurisdictions, but spend less time directly teaching students, and more time on activities such as lesson planning, collaborating with other colleagues, engaging in lesson study, meeting with parents, leading extracurricular activities (NCEE, n.d.b). Lesson study is based on collaboration in the professional community and encourages teachers to research their own practice through planning lessons together and observing each other in lessons (Doig & Groves, 2011). It appears that teachers in Japan collaborate a lot with each other. For instance, lower secondary school teachers are expected to meet with each other to discuss how to help students who are struggling (NCEE, n.d.b). Teaching is a highly selective career. The NCEE (n.d.b) reports that all teachers must have a degree from a higher education institution, whilst Tonga et al. (2019) suggest that individuals can train via an open system, which enables them to work as early childhood education teachers and primary school teachers or by obtaining a university degree to work in primary and secondary schools. Candidates applying to train as teachers in Japan must complete two assessments: a university entrance exam, which assesses their academic abilities in maths, science and a language, and a practice exam, which considers their teaching abilities, interpersonal skills and communication skills. Furthermore, applicant must pass the National University Entrance Exam after secondary school, which assesses their levels in Japanese, foreign language, maths and social sciences (Mete, 2013 as cited in Tonga et al., 2019). Such selective admission processes could be due to the fact that Japan (and China) are highly populated and so assessment and selection criteria are needed in admitting candidates to courses (Tonga et al., 2019).

Isozaki (2018) reports two types of training institutions: type A (focused on professionalism and practical application over theory) and type B (more academic) and claims that there are no professional standards for teachers, except the curriculum framework (the minimum number of credits of teaching subject specialties and professional studies for a teaching certificate and the minimum requirement of professional studies since 1998), which is different to other jurisdictions (see Appendix D). Furthermore, in Japan (and China), teacher candidates must pass examinations to be employed as teachers. In-service teachers experience a mentoring system – they are supported by other staff at their school, attend a one-year compulsory in-service education programme, during which they receive 60 days of in-school training with a consultant teacher, exchange ideas, observations, analysis of lesson plans and materials and activities planning (OECD, 2016 as cited in Tonga et a., 2019). TALIS results have indicated that Japanese teachers take part in continuing professional development more than the average (OECD, 2014 as cited in Isozaki, 2018). Additionally, out-of-school support is also available in the forms of training in ethics, responsibility, teaching discipline and guidance for students, provided at education centres (Orakçı, 2015 as cited in Tonga et al., 2019). Japan (similarly to Singapore, China and Estonia) views teacher's development needs as continuous, and Tonga suggests that this could contribute to their international success.

Science-specific features

Who has contributed to the development of the science curriculum?

The Ministry (MEXT), university professors and the Central Council for Education establish broad guidelines for content of each subject from kindergarten to secondary school (NCEE, n.d.b). The MEXT revises the national curriculum every decade, and they have been revised eight times since their first implementation in 1946 (TIMSS & PIRLS International Study Center, n.d.). Ministry specialists prepare teacher guidebooks (with input from teachers) (NCEE, n.d.b).

When do students study science and when is science compulsory?

Science is studied from primary school (starting in grade 3) up to senior secondary schools (Nakamichi & Katayama, 2018; NCEE, n.d.; TIMSS & PIRLS International Study Center, n.d.), but it is compulsory from primary to the end of lower secondary school (TIMSS & PIRLS International Study Center, n.d.). Lau (2014) writes that about 12.2% of Japanese students had 4 or more hours of science lesson each week (compared to 32.7% OECD average). Furthermore, Lau (2014) found that just over 3% of students had 2-4 hours of out-of-school science lessons a week (compared to 8.2% OECD average), and just over 5% had 2-4 hours of self-study/homework each week (compared to 18.6% OECD average) (see Appendix D). However, the literature did not reveal how many hours per week students study science at each educational level, therefore Lau's (2014) finding should be taken with caution as it used data from the 2006 PISA and may be outdated now. Furthermore, Japan has developed “Super High School” programmes in a few subjects, including science (with focus on STEM subjects). These programmes are small and represent only 2% of high schools in Japan. They are highly prestigious and provide additional opportunities such as lectures delivered by college professors (NCEE, n.d.b). There may also be differences in the number of hours students in these programmes learn science compared to students who do not attend such specialised courses.

Influence of research on science education

Concerning the impact of research and evidence, Nakamichi and Katayama (2018) state that over the last curriculum revision, biology education at upper secondary school has been updated to reflect the quick progress in biological research, thus moving it closer to biology education at higher (tertiary) level. However, this review did not reveal how important research and evidence are supporting the development of science curriculum in Japan at other educational stages or in other science subjects.

Features and aims of the science curriculum

Nakamichi and Katayama (2018) state that the key philosophy of the Course of Study (CS) is “Zest for life” (p. 8). In 1989, in response to criticisms of the education system, the new CS in Japan de-emphasised science and re-emphasised social issues, such as individualisation (a move towards individuality), internationalisation (international understanding, foreign language education, creating a study abroad system and educating children who have come back from abroad) and information literacy (Kumano, 2009; MEXT, n.d.). This was partly due to reports suggesting that children were not being adequately socialised, which in turn had impact on local communities, and children’s ethics, social skills and independence (Cave, 2001).

Kumano (2009) states that there has been a reform around the theme of science-technology-society (STS) in Japan, and so the national curriculum has made attempts to follow this theme. The STS theme is around emphasis on social issues, such as individualisation and information literacy, and so the national curriculum at the end of the 1980s de-emphasised science and emphasised issues social issues more. Kumano (2009) suggests that more science education researchers, government researchers and science teachers are becoming involved with STS in Japan, but that the definition of STS is not consistent in Japan and that understanding STS in an academic way and using it in science lessons are very different.

The 2002 reform of the CS saw a new framework of subjects in high school science, including *Basic Science* (which intended to help students learn the history of science, the relationships between human life and science to develop scientific perception and thinking), *Comprehensive Science A* (researching natural phenomena related to daily life, e.g., materials and energy), and *Comprehensive Science B* (studying biological and natural phenomena in the global environment) (Kumano, 2009). The 2008-09 reforms included changes in the number of credits and subjects from the 1999 CS. The 2008/09 subjects included: *Science and Our Daily life* (2 credits), *Basic Physics, Chemistry, Biology and Earth Science* (2 credits), *Advanced Physics, Chemistry, Biology and Earth Science* (4 credits) and *Science Project Study* (1 credit), with the first and last being newly introduced in 2009 and intending to increase inquiry abilities and interest in nature, science and technology (Nakamichi & Katayama, 2018, see Appendix D or Table 1 and 2 in the paper for more detail). The NCEE (n.d.b) indicates that the 2012 revision has a subject-area focus, but aims to develop cross-curricular competencies including problem-solving, creativity and good learning habits by emphasising active learning in subjects. TIMSS and PIRLS International Study Center (n.d.). states that the overall objectives for grades 3-6 science aim to

> "enable students to become familiar with nature and to carry out observations and experiments from their own perspective; help students develop their problem solving abilities; nurture students' affection for the natural world; help students develop a realistic understanding of natural phenomena; and encourage students to embrace scientific perspectives and ideas". (para 3)

The overall objectives in science for students in lower secondary school (grades 7-9) aim to

> "enable students to take an active interest in natural things and phenomena and to carry out observations and experiments with a sense of purpose; help students to develop the ability to perform investigations scientifically and to develop a positive attitude about these investigations; help students to deepen their understanding of natural things and phenomena; and help students to develop scientific ways of observing and thinking". (para 7)

For more information on the specific objectives, topics and content relevant to the objectives mentioned above, please see the TIMSS and PIRLS International Study Center (n.d.) website. Nakamichi and Katayama (2018) state that in the present biology curriculum for upper secondary schools, two new topics (*Science and our daily life* and *Science project study)* aim to increase students' interest in nature, science and technology and enrich students' inquiry abilities.

Place of scientific literacy in the curriculum

With regards to the place of science literacy in the curriculum, the upper secondary curriculum includes science inquiry and social science inquiry courses (NCEE, n.d.b). Nakamichi and Katayma (2018) mention "aspects of scientific literacy" in relation to *Basic of molecular biology (DNA), Health* and *Environment* (see Table 3 on page 9), but it is unclear what this means in relation to scientific literacy and its development. It could potentially link to the contexts for items assessing scientific literacy, which have been grouped into five applications of science and technology: *health and disease, natural resources, environmental quality, hazards* and *the frontiers of science and technology* (see Table 1 above), but this is speculative. This review did not find much more on the place of scientific literacy in the Japanese curriculum, potentially as only a few sources that were found were relevant.

Opportunities for science learning outside of the classroom

It was mentioned above that one of the three curricular categories is 'special activities'. These include "activities and ceremonies that emphasize teamwork and cooperation as such as graduations, field trips or school concerts" (Standards and Curriculum, para 5). This suggests that students may experience extracurricular activities, but the literature did not list any specific elements or opportunities in science.

Science teaching (pedagogy) and how science is experienced in classrooms

Nakamichi and Katayama (2018) state that the new curriculum will introduce more innovative methods, such as active learning, which introduce competency-based learning and shift away from the traditional content-based learning. Active learning is a broad term that describes teaching and learning methods which encourage students to actively participate in the study process. These may include discovery learning, problem solving learning, experiential learning, investigative learning through group discussions, debating, collaboration and group workshops (MEXT, as cited in Hiroshima University, 2003). Active learning focuses on how students learn rather than what they learn, and it encourages students to 'think hard' rather than receive information in a passive way. Enquiry-based learning can be a useful technique for encouraging active learning (for information on enquiry-based learning, see pp. 24-25) (Cambridge Assessment International Education, n.d.). The literature did not clarify if there is a connection between active learning and competency-based teaching. The OECD (2018a) writes that Japan recognises the importance of updating teaching to "foster competencies for the 21st century" (p. 1) and that it wants to develop cross-curricular skills (problem-solving, creativity and good learning habits) in the new curriculum (to be implemented from 2020-2022) by using active learning strategies to develop competencies around three themes: "motivation to learn and apply learning to life, acquisition of knowledge and technical skills, and skills to think, make judgements and express oneself" (p. 1).

However, it is not clear if the planned implementation of the new curriculum between 2020-2022 actually took place considering that the COVID-19 pandemic may have impacted its implementation. Additionally, the evidence accessed and reviewed here did not give very clear indications about what the key features of the Japanese science curriculum are, such as competencies or whether the curriculum emphasises lower/higher levels of cognition.

In comparison to other jurisdictions' teaching/learning approaches, Lau (2014) suggests that science-related pedagogy in Japan (application of concepts, student-teacher interactions, hands-on-activities and investigations), was more traditional than the OECD average and "more traditional than the Chinese communities" (p. 9), with less application, less interactivity, and few hands on and investigative activities. However, Lau did not find negative impact of this traditional pedagogy on cognitive performance. Lau and Lam (2017) state that most schools in Japan tend to emphasise university entrance and preparation and a "one-way flow of information" (Morimoto, 2015, as cited in Lau & Lam, 2017, p. 2144), indicating a more teacher-led pedagogical style. Japan was also found to be below the OECD average in inquiry-based instruction. Additionally, 50% of Japanese students reported that class discussions did not happen, 40% reported that they never do any experiments, and some reported not being given the opportunity to explain their ideas in lessons. It is important to keep in mind that this is only one study, which used science data from students who completed the 2015 PISA test. The authors report that the final sample included between 4,000 – 20,000 students, and therefore may not be entirely representative of the experiences of all students in Japan. Furthermore, the teaching practices were reported by students rather than teachers or independent observers.

Nakamichi and Katayama (2018) write that the new biology curriculum in Japan (which was intended on being implemented in 2020-2022) could pose challenges for teachers, as it requires a shift from a traditional, teacher-centred style to a more student-centred teaching. This may be time consuming and difficult if teachers have not been trained in such approaches. Furthermore, teachers at upper secondary school may choose a more traditional delivery method to cover the content and to prepare students for university examinations. Some teachers may find it difficult to conduct more experiments and to engage with the more recent biology content if they have not been trained in it. They suggest that changes to teacher training and development, such as greater emphasis on student-centred, active pedagogies, promoting ICT use and modernising science equipment could support teachers in engaging in more active learning (see Appendix D for more information).

Student performance in specific components of science in PISA

Lau and Lam (2017) looked at the mean scores of HPJs on different competencies and kinds of scientific knowledge in the 2015 PISA. They found that Japan performed second best after Singapore in areas linked to *explaining phenomena scientifically* (EP), *evaluating and designing scientific enquiry* (ED), *interpreting data and evidence scientifically* (ID) (scientific competency domain). Japan also had the second highest mean scores after Singapore in *content knowledge* (CK) and *procedural and epistemic knowledge* (PEK) (scientific knowledge domain) and was the second highest performer in both domains of scientific competency and scientific knowledge in 2015 (see Table 5 on p. 2136). The authors state that Japan tended to perform similarly to Western regions (better in areas linked to scientific investigation). This is surprising considering that “in general … Japan and Korea (tend to be) more traditional and didactic” (Lau & Lam, 2017, p. 2144) and that about 40% of students in Japan reported never doing experiments. Additionally, it is surprising considering that Japan scored below the OECD mean on enquiry-based instruction. This demonstrates the challenges in explaining Japan’s PISA performance with findings about the classroom pedagogies and instruction, as evidence is inconsistent and mixed. Some suggest a very traditional and teacher-led style (e.g., Lau, 2014), whilst other findings suggest that teacher-directed teaching is below the OECD average (Lau & Lam, 2017). Another limitation of this evidence is that it is not from the latest round of PISA, which (once available) may offer different insights.

Estonia

General education system

Stages of education

Estonian children can attend non-compulsory preschool between the ages of 4 and 7 years old. Compulsory schooling starts at the age of 7 and ends at 17 (NCEE, n.d.a). From the age of 7 years old, children start to attend basic schools, which includes primary school and lower secondary school (grades 1-9 or ages 7-16). Basic education is further split into:

- stage 1 (grades 1-3),
- stage 2 (grades 4-6) and
- stage 3 (grades 7-9).

At the end of grade 9, students who complete the curriculum and pass a set of examinations earn their basic school certificate. To graduate from basic school, students must pass three exams: Estonian language or Estonian as a second language, mathematics, and a subject of choice, and must complete a creative assignment (Kori, 2022). Students then move onto upper secondary school (grades 10-12 or ages 16-19). To graduate from upper-secondary school, students must complete the curriculum on (at least) a satisfactory level, pass the state examination of Estonian language or Estonian as a second language, mathematics and a foreign language, pass the upper-secondary school examination and complete a research paper or practical (Kori, 2022). Estonia follows the comprehensive education system with compulsory schooling ("basic education", where all students have a similar education) between grades 1 and 9 (Tire, 2021). After grade 9, students are streamed into vocational and academic tracks 9 (Tire, 2021). In upper secondary school students can choose a vocational or an academic program, with the majority selecting academic programs (NCEE, n.d.a, Tire, 2021).

Languages

The official language of Estonia is Estonian, although more than 25% of Estonian households are Russian speaking (NCEE, n.d.a). This is also seen in the education system, where two types of schools exist: those with Estonian as the main language of instruction and those with Russian as the main language of instruction (Tire, 2021).

Is education centralised or de-centralised?

Considering the centralisation of the education system, schools are expected to follow the national curriculum to develop their own school-based curricula (NCEE, n.d.a). However, Tire (2021) suggests that schools are usually owned by local municipalities and therefore have quite a lot of autonomy, can decide on their culture, goals and identity, teachers can decide on the textbooks and methods they use to teach, there are no inspections, and the state interferes only in some cases, such as a complaint. Furthermore, they suggest that schools in Estonia "have enjoyed a lot of autonomy for decades" (p. 115), with little disturbances from inspections but an internal strive to improve and to offer the best education for children. Eurydice (n.d.b) suggests that the "Estonian education system is decentralised. The division of responsibility between state, local government and schools is clearly defined" (Organisation and governance, para 5). It therefore appears that Estonia may fall somewhere in between centralisation (with schools expected to follow national curriculum) and de-centralisation (with teachers and schools given autonomy to develop school-based curricula).

Curricular reforms, key features and aims of the general curriculum

Tire (2021) states that the national curriculum is updated approximately every decade and stipulates the learning outcomes that students should achieve (master) at each stage of education. In the 1990s, Estonia's Ministry of Education and Research (MoER) developed a new curriculum focused on problem-solving, critical thinking and information technology, which included student competencies and introduced a set of cross-curricular topics to be embedded across subjects (NCEE, n.d.a). In 2002, the first major revision of the national curriculum cut the required content in order to leave more time to develop competencies.

The next key revision in 2011 split the curriculum into two parts – one for basic education and one for upper secondary and introduced a new requirement for graduation – a cross-disciplinary creative project for those in basic school and a research project for those in upper secondary school. This update also saw more attention paid to developing subject strand competencies, general competencies and cross-curricular competencies that teachers should include in their lessons (Tire, 2021). This reform is present today, although has been revised numerous times, with the 2014 revision seeing updates to the competencies and specifying that they should be taught across and within subjects through out-of-school experiences such as visits to cultural institutions or museums and extracurricular activities (NCEE, n.d.a). The competencies include: *cultural and value competences*; *social and civic competencies*; *competency for self-determination*; *learning competence*; *communicative competence*; *mathematical, natural science and technological competences*; *entrepreneurship* and *digital competence* (Eurydice, n.d.b).

In 2014, the *Lifelong Learning Strategy* was adopted by the Estonian government with the aim of guiding education reforms at all levels, starting with pre-school and going all the way up to adult learning. The strategy suggests that focus should be on the "acquisition of learning skills and creativity; developing competent and motivated teachers and school leaders; creating lifelong learning opportunities matched to the needs of the labour market; and ensuring a digital focus and equal opportunities to participate in lifelong learning" (NCEE, n.d.a, para 4). The curriculum for basic education has eight compulsory subjects: language and literature, mathematics, foreign languages, natural science, social studies, art and music, technology, and physical education, as well as elective subjects such as religious studies, informatics, career education and entrepreneurship. The national curriculum for upper secondary education includes seven compulsory subjects: language and literature, mathematics, foreign languages, natural science, social studies, art and music and physical education, plus six electives – religious studies, national defence, economic and business studies, philosophy, career education and "bases of inquiry" (investigative research) (NCEE, n.d.a, Standards and Curriculum, para 4).

The Estonian curriculum is based on the idea that students should possess a broad worldview, and many schools include subjects such as coding, robotics, cooking and woodwork classes, with mixed ability groups of boys and girls working and problem-solving together (Tire, 2021). The education system in Estonia is based on the Lifelong Learning Strategy, which has five goals, including

> "change in the approach to learning, competent and motivated teachers and school leadership, concordance of lifelong learning opportunities with the needs of the labour market, a digital focus in lifelong learning (including using modern technology for learning and teaching, improving digital skills of the population), and equal opportunities and increased participation in lifelong learning". (Ministry of Education and Research, n.d., cited in Kori, 2022, p. 389)

The curriculum has developed from an outcome-oriented to a competency-oriented one (see Tire, 2021 in Appendix E). The current curriculum contains competences that are developed in all subjects and through extracurricular activities. The curriculum suggests that the competences should be taught across and within subjects, through experiences occurring outside of school and extra-curricular activities (NCEE, n.d.a). The competences include:

1) “cultural and value competences,
2) social and civic competences,
3) self-determination competence,
4) learning competence,
5) communication competence,
6) mathematics, science and technology competences,
7) entrepreneurial competence,
8) digital competence” (Basic school national curriculum, 2011; Upper-secondary school national curriculum, 2011, as cited in Kori, 2022, p. 390).

The curriculum also includes “several cross-cutting topics between the science subjects”, including

1) “environment and sustainable development,
2) citizens’ initiative and entrepreneurship,
3) cultural identity,
4) information environment,
5) technology and innovation,
6) health and safety,
7) values and morals” (for basic school), and
8) “lifelong learning and career planning” (added in upper-secondary science curriculum) (Kori, 2022, p. 390).

Textbooks, resources and the use of technology in education

With regards to textbooks, Tire (2021) suggests that teachers can decide on what textbooks they use in lessons. Additionally, textbooks are free. In their study of the differences in performance between Estonian and Russian speaking schools, Henno and Reiska (2013) suggest that there is a need for more research as in cases where one language group outperforms the other, both groups often receive instruction in their mother tongue, use the same curriculum and textbooks (see Appendix E for more information).

In addition to printed textbooks, schools have access to free digital materials, including assessment banks, school administration software, textbooks and workbooks (Kori, 2022; Tire, 2021). By the early 2000s, all schools in Estonia had computers and Internet access and teachers had been offered training to build their technology skills. Furthermore, in 2014, the national curriculum stated that all students should develop digital literacy (NCEE, n.d.a). Kori (2022) comments on the variety of digital materials available to teachers of science, such as one of the largest digital repositories called e-schoolbag (www.e-koolikott.ee), which includes resources from kindergarten all the way up to vocational schools. Teachers can access this freely to search for learning materials and share their own materials (such as tasks, games, worksheets, videos). These learning materials are linked to the national curriculum. Additionally, teachers and students have access to digital textbooks and workbooks (e.g., https://www.opiq.ee/). Schools are making more use of emerging technologies in teaching science, including but not limited to computers, laptops, tablets, robotics tools, sensor-based technologies, video equipment, and in very few cases even drones, augmented reality (AR), virtual reality and AI tools (Kori, 2022). Kori (2022) states that the last few decades have brought technology-enhanced learning environments (e.g., The Go-Lab platform or Young Researcher) to science classrooms in Estonia.

Concerning the availability and use of technology, Kori (2022) states that some Estonian schools have equipment that supports inquiry-based learning, such as sensor-based technologies. Some teachers find ways to teach outside of classrooms and use mobile technologies, but an analysis of outdoor learning scenarios developed by Estonian teachers did not support higher order knowledge building (Mettis & Väljataga, 2019 as cited in Kori, 2022).

Equality in education

The comprehensive school system in Estonia aims to provide all students with the best quality education regardless of background. Estonia has a high proportion of "resilient students" – students from disadvantaged backgrounds who perform highly, above the OECD average (Tire, 2021). Tire (2021) states that the Estonian education system provides for all students equally, regardless of socio-economic background (e.g., students from poorer families receive financial help). Many schools also have their own psychologist, speech therapist and other specialist staff, and many students stay after lessons to complete homework with supervision and to take part in free extra-curricular activities. Perhaps these factors contribute to the high performance of Estonian students regardless of their socio-economic situation. For instance, according to Tire (2021), 15.6% of Estonian students from disadvantaged backgrounds fall into the best performing 25% of students. Furthermore, the mean score of those from the bottom quarter of socio-economic status is 497, which is above the OECD average. It suggests that students from disadvantaged backgrounds manage to perform very well in the PISA assessment, even overtaking some students from most affluent backgrounds in many other countries (ibid).

Teacher training and professional development

Following on, the literature presented a lot of information about training and development of Estonian teachers. The NCEE (n.d.a) states that teacher training in Estonia takes five years and ends in a Master's degree. In 2012/13, Estonia eliminated tuition fees for all full-time courses, and part-time courses in areas which were experiencing shortages, such as teaching. At the same time, the standards required for admission to teacher education programmes were increased (ibid). In 2005 the Ministry developed national standards for teachers and updated them in 2013 and 2017. Teacher preparation curricula have been updated to align with teacher competencies from the teacher professional standards. In 2015, an accelerated programme was developed, which allows those with Master's degrees to obtain a teaching qualification by showing skills through a portfolio review process, which is based on the teacher professional standards (ibid). Students are admitted to teacher training programmes based on grades and "professional aptitude" assessed on the basis of a school-designed entrance exam, scores on the national upper secondary graduation examination, an interview or group discussion, but specific entrance criteria vary across courses. In general, teacher training includes: general education studies; studies linked to the subject and professional study (practical training, psychology, pedagogy and education science). Vocational teachers generally require a bachelor's degree, but vocational schools may employ teachers who do not possess formal teaching qualifications up to a fifth of their workforce. This allows industry experts with experience in the subject to teach (ibid).

Before 2013, teachers had to complete at least 160 hours of professional development every five years, and vocational teachers had to complete at least two months of professional training during every three-year period. The 2013 professional standards update saw the prioritisation of “continuous education of teachers”, and the elimination of specific requirements for the length of training. Instead, teachers are responsible for assessing their own learning needs and collaborating with school principals on what professional learning they wish to pursue. About 1% of government funding for teacher salaries is used to fund professional learning, and municipalities can offer to provide additional funding to schools (ibid).

Tonga et al. (2019) states that primary and secondary teachers must possess a Master’s degree, and Kori (2022) supports this. In addition to being taught pedagogical and content knowledge, pre-service teachers are also taught additional aspects, such as skills for inquiry, communication, ICT, other languages. Teacher candidates must complete two assessments to enrol on teacher training courses: a university entrance exam (which assesses academic achievement in maths, language and science) and a practice exam (which assesses teaching abilities, interpersonal skills and communication skills) (Mete, 2013 as cited in Tonga et al., 2019). Admission requirements in Estonia are managed by universities and a quota system is employed to determine the number of applicants accepted to teacher training programs. Qualified trainees do not need to sit additional examinations before starting their employment in schools. Focus is given to trainees entering the teaching profession, and teachers must complete a period of in-service education, which includes a mentoring system that prepares them for working as a teacher. They also attend courses, seminars and training organised by universities and other non-governmental organisations (see Appendix E). Tire (2021) also writes that teachers can access in-service courses and training programmes for free and can join subject teacher networks to be updated on important changes and information, as well as to communicate with others. Kori (2022) suggests that Estonian teachers tend to be older and despite possessing a lot of experience, they may find new technologies and innovations or teaching methods in science a slight challenge.

The influence of culture on education

It is also important to illustrate that culture and social factors have also influenced the Estonian education system, and thus factors such as culture cannot be taken out of the picture. Tire (2021) suggests that during the Soviet time, education remained Estonian, but Russian language was added to the curricula and education was influenced by Soviet ideology. Estonia gained its independence in 1991, around the time when various changes to the curriculum were established. Furthermore, Finnish education had influence on processes in Estonia, partly due to language similarities and exchanges with Finnish universities. Estonia looked at the Finnish curricula, teaching materials and practices. These are only some of the cultural influences and elements that may have impacted on the education and curriculum in Estonia. Tucker (2015, as cited in Tire, 2021) summarises the importance of history and culture by saying;

> “the fact that Estonia is among the top performers in PISA does not appear to be the result of education policies purposed since Estonia gained its independence, but rather the result of hundreds of years of political, social and educational development which ended up supporting a

> strong commitment to education as well as tradition of very high education standard, very demanding curriculum, high quality examinations built directly on the curriculum, highly educated teachers, and most of the other drivers of high performing national education systems”. (p. 118)

Although there most likely are other cultural factors that play a part in Estonia’s high performance, which have not been mentioned in this summary or found in this review.

Science-specific features

The literature search did not bring up much information about science education and curriculum in Estonia. Furthermore, as curriculum documents were not used in this literature review, what is outlined may present a limited account of science education in Estonia.

Who has contributed to the development of the science curriculum?

Curriculum development in Estonia is the responsibility of the Ministry of Education and Research, which in turn commissions a specific group of people to work on developing the curriculum. Various bodies have strong influence on curriculum development, including educational researchers at universities, practitioners at schools and the Educational Forum (Kori, 2022). The Educational Forum is an advisory body made up of those with interest in education (students, teachers, parents, employers, politicians), which offers advice on issues in education. It appears to be a non-governmental organisation (Loogma, n.d.; Ministry of Education, 2001; OECD, 2016c).

When do students study science and when is science compulsory?

In compulsory basic school (primary and lower secondary or ages 7-16 years/grades 1-9), students will study natural science among other compulsory and elective subjects (NCEE, n.d.a). In grades 1-7, all study general science, in grades 7-9, biology and geography are taught, and in grades 8-9 students study chemistry (Kori, 2022). In upper secondary school (ages 16-19 years/grades 10-12), students can choose a general secondary school path or a vocational path. To graduate from upper secondary school, students must complete the curriculum and pass the state examinations in Estonian, mathematics and a foreign language. Kori (2022) does state that “science education in Estonian basic and upper-secondary schools follow the national curriculum” (p. 389). At upper secondary level, students are taught biology, physics, chemistry and geography, as well as cross-cutting topics. This suggests that at upper level, students study science subjects, but do not need to pass these in their final examinations to graduate upper secondary school.

In basic school, the national curriculum suggests that students who are at stage 1 (grades 1-3) should spend 3 hours studying natural sciences per week. In stage 2 (grades 4-6), this increases to 7 hours. In stage 3 (grades 7-9) it decreases to 2 hours per week, however, the curriculum then splits science into geography, biology, chemistry and physics, each with the following numbers of teaching/learning hours: geography – 5 hours, biology – 5 hours, chemistry – 4 hours, physics – 4 hours (Eurydice, n.d.a).

Influence of research on science education

Kori (2022) suggests that research plays a part in the Estonian education system. The Estonian Ministry of Education and Research supports science-based policy making and is involved in researching, analysing and evaluating the educational landscape, as well as in commissioning studies from researchers and experts at universities. The Ministry develops an annual plan for research projects. For instance, the 2020 plan includes participating in international studies such as TALIS (the OECD Teaching and Learning International Survey completed by teachers and principals), PISA, and others, as well as researching the use of digital learning materials, learner's individual learning paths, effects of anti-bullying schemes in schools and youth work (Ministry of Education and Research, n.d., as cited in Kori, 2022), The research council also offers research and mobility grants to support high level projects and to support the next generation of researchers (Estonian Research Council, n.d. as cited in Kori, 2022).

Features and aims of the science curriculum

The science curriculum for basic and upper-secondary school highlights the use of technology at all grades to aid learning and to develop digital literacy (NCEE, n.d.a) and developing inquiry skills in students/inquiry-based learning (Kori, 2022), meaning that students follow methods similar to those employed by scientists to construct their knowledge (Keselman, 2003, as cited in Kori, 2022).

Place of scientific literary in the curriculum

With regards to the place of scientific literacy in the curriculum, the literature examined here did not specify this, but mentioned that science education has a key role in developing "active informed citizens who are scientifically literate, aware and able to conceptualize from a scientific perspective, who are willing to take action in scientific activities, and … contribute to science embedded social issues" (Chowdhury et al., 2020a, as cited in Kori, 2022, p. 394). Kori (2022) also states that there is a change in focus that emphasises socio-scientific issues, thus "brings science education outside the classroom" (p. 394). This is promoted by citizen science - a new approach seen in Estonian schools aimed at "regular people … carrying out scientific research together with professional scientists" (Silvertown, 2009 as cited in Kori, 2022, p. 394). This does not specifically refer to the place that scientific literacy has in curriculum documents but refers more to the general place of science education.

Opportunities for science learning outside of the classroom

With regards to science opportunities outside of school, Kori (2022) states that larger cities have science and technology venues, such as the Science Centre AHHAA in Tartu, which offers workshops, science theatre shows, planetarium and special programmes for schools. Tallinn has the Energy Discovery Centre with over 100 exhibits designed to help in the study of physical phenomena such as electricity and programmes for schools. Both of these science centres collaborate with universities, but other institutions also offer schools visits and competitions for students. For instance, each year, a student research festival takes place, where students make poster presentations about their research and take part in science shows and workshops (Estonian Research Council, n.d., as cited in Kori, 2022). The Estonian Research Council has also developed the TeaMe+ programme with the aim of increasing informal science activities (after school activities).

Science teaching (pedagogy) and how science is experienced in classrooms

With regards to the teaching/learning approaches adopted by Estonian teachers, Tire (2021) reports on findings from the 2018 TALIS data and suggests that Estonian teachers tend to be more traditional and follow well established practices in everyday teaching. They also suggest that teachers assess progress made by students frequently, but do not tend to use modern approaches (where students evaluate their own progress) much (self-evaluation is used by 28% of teachers in Estonia compared to the 41% OECD average of other jurisdictions). Kori (2022) comments on several challenges, including teachers' claims of how busy they are following the topics set out in the curriculum and not having the time to use new approaches in lessons, such as setting tasks that develop various competencies. Henno and Reiska (2013) conducted a comparison of Estonian and Russian speaking schools, as there are differences in science performance between the two, with Estonian-instruction schools outperforming Russian-instruction schools in science. They reported that in general, teachers in Estonian-speaking schools had more constructivist views, supported traditional/direct instruction and constructivist approaches to teaching, whereas teachers in Russian-speaking schools tended to show more belief in knowledge transmission, direct instruction and fact-based teaching (Loogma et al., 2009 as cited in Henno & Reiska, 2013). Henno and Reiska (2013) found that in Russian-instruction schools, students who performed higher than expected tended to have teachers who focused more on application of models and hands-on activities. Students who performed well in Estonian-instruction schools tended to report that they conducted student investigations but had lower instrumental motivation in science and general interest in science in comparison to students from Russian-instruction schools whose performance was higher than expected. The researchers summarised that Estonian teachers in different language instruction schools may implement different teaching approaches, with more fact-based teaching and weaker development of meta-cognitive skills being more common in Russian-language instruction schools (Säälik, 2012, as cited in Henno & Reiska, 2013). This suggests that there are between-school differences that need to be considered when making interpretations about teaching instruction and approaches in jurisdictions.

With regards to classroom pedagogy and teaching approaches, Lau and Lam's (2017) analysis of the top 10 performing jurisdictions in 2015 PISA found that teacher-directed instruction was less common in Estonia compared to other nations. Estonia also had relatively low scores on adaptive instruction[5]. Enquiry-based instruction was seen as not commonly used in Estonia (see Table 6 in Lau & Lam, 2017). Estonia scored relatively low on the practice of teachers explaining scientific ideas (Lau & Lam, 2017). However, Estonia scored relatively high on whole-class discussions taking place with the teacher and on students being given opportunities to explain their ideas compared to Japan and Macao. Estonia also saw a higher frequency of teachers explaining how science is relevant to daily lives. With regards to students spending time in laboratories conducting practical experiments, Estonia scored lower than the other four jurisdictions of interest to this review. In terms of students being allowed to design their own experiments, all jurisdictions scored

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[5] Adaptive instruction in the context of Lau and Lam's (2017) paper refers to "science teaching… largely directed by the teacher… often adapted to the needs of students" (p. 2137).

relatively low in comparison to other items. Estonia (1.56) also scored just below the OECD mean (1.63).

Kori (2022) also suggests that for some established teachers, using new technologies and teaching methods may be a challenge, and sometimes teachers do not use them. This finding suggests mixed evidence as to the extent to which inquiry-based teaching/learning is present in Estonian classrooms and poses a slight challenge when considering that the science curriculum emphasises the use of technology to develop students' inquiry skills (Kori, 2022). It also supports a pattern that has come out of the reviewed evidence for the jurisdictions considered so far, which is that even if a curriculum mentions inquiry-based learning, there is no guarantee that inquiry instructions/approaches will be adopted in classrooms.

Student performance in specific components of science in PISA

Lau and Lam (2017) also reported that Estonia tended to perform better in the *evaluate and design scientific enquiry* (ED) element of PISA, which may reflect "a stronger emphasis on scientific inquiry" (p. 2135). However, they analysed the 2015 science data, thus it cannot be concluded that Estonian students performed better in ED in the 2018 round of PISA. Henno and Reiska (2013) report that in the 2006 PISA, students in Estonian-language schools performed better than those in Russian-instruction schools in all main science competencies, including: explaining phenomena scientifically, identifying scientific issues and using scientific evidence. This illustrates that there may be within-jurisdiction/between-school differences in performance on specific elements of science. Again, this review does not present data on the most recent (2018) science component of PISA. Analyses would need to be carried out using the 2018 data to show what areas within the science component Estonian students performed better in and if differences between Estonian and Russian-speaking school students still exist.

Discussion

This section will present some key commonalities and differences between the five jurisdictions that are worth considering when attempting to answer the question in the title – what can we learn from high performing jurisdictions?

Common themes, differences and limitations

Common themes

This review revealed some common themes between the five high performing jurisdictions, including:

- mixed evidence on inquiry-based learning/teaching and the extent to which there is consistency between what the written and enacted curriculum presents regarding inquiry,
- scientific literacy recognised in the curricula of some of the HPJs as important,
- mentions of the value of research and evidence in informing science curriculum development,

- emphasis on high quality teacher training and professional development,
- science opportunities outside of school,
- pedagogy and students' reported experiences,
- distribution of types of knowledge in curriculum document,
- recognising the importance and influence that culture has on education systems and curricula,
- reports of centralised education systems in at least 3 of the 5 HPJs (with caveats).

These main themes will now be explored in more detail below and in the considerations section. These are not to be taken as the main reasons for high performance of these jurisdictions, but they demonstrate some of the areas (themes) mentioned in the literature, around scientific literacy, performance and the five HPJs of interest. However, more research is needed to clarify their role in the success of HPJs as some of the findings are almost counter-intuitive. For instance, Wei and Ou's (2019) analysis found that Macao and mainland China's science curriculum documents tended to emphasise lower levels of cognitive processing, which focus on memory of factual and conceptual knowledge.

Mixed evidence on inquiry-based pedagogies

The first theme is that although literature concerning many of the five jurisdictions refers to inquiry-based learning, the evidence on whether inquiry-based learning happens in classrooms is very inconsistent and mixed (e.g., Lau & Lam, 2017). Despite research suggesting that curricula in these jurisdictions promote inquiry-based learning/teaching, we cannot assume with certainty that it will be consistently enacted in every school, or classroom, by every teacher and at all times (e.g., Deng & Gopinathan, 2016; Lau & Lam, 2017; Lee, 2018). Furthermore, Lee (2018) writes that although inquiry teaching is seen as important in Singapore, research has found that in-service teachers were very aware of their institutional responsibilities in preparing students for exams, which reduced the overall drive to engage in opportunities to learn science through inquiry. This suggests that there may be discrepancies between what the written curriculum states and what is happening in the classroom through the enacted curriculum. Thus, although the literature may indicate that something is happening, in practice, it may be happening to a lesser extent and many contextual factors need to be considered before drawing conclusions about the specifics of a jurisdiction's education system and its success.

Considering that there are different definitions of inquiry-based teaching, it may pose issues for identifying when teachers use inquiry approaches. A common way of describing inquiry-based teaching is that is includes hands-on activities, promotes higher order skills, creative thinking and does not just develop basic skills (e.g., Sandoval & Reiser, 2004, as cited in Tang et al., 2020). Mäeots et al. (2011, as cited in Kori, 2022) defines inquiry-based learning as "a process of discovering new relations between different variables through formulation hypothesis and testing the hypothesis in experiments or by collecting data through observations" (p. 390). Does this therefore mean that if students are carrying out science experiments in school, they are engaging in inquiry-based learning? Or would they also need to show that they are developing higher order thinking skills? Savery (2015, as cited in Kori, 2022) conceptualises inquiry as an active, student-centered approach which emphasises questioning, critical thinking and problem solving. With various definitions, what certainty do we have that research into inquiry-based teaching is measuring the same thing? To what extent can we be sure that students are active recipients of learning when they engage in experiments, rather than simply carrying out procedures they observed from their teacher? Inquiry seems to be a complex concept that may be difficult to measure. This means that it may be difficult to identify when individual teachers are taking an inquiry approach. It also makes it difficult to disentangle the relation between inquiry-based approaches and PISA scores.

Recognition of scientific literacy in curriculum documents

Another common theme in the literature is that the development of scientific literacy is mentioned as an aim of the curricula of China, Singapore and Macao. If scientific literacy is promoted in the curriculum (and perhaps enacted in the classroom), it could be contributing to the high performance of these jurisdictions on the assessment of scientific literacy in PISA. However, this is speculative, and more research is needed to investigate how scientific literacy is promoted in the classrooms of the jurisdictions that mention it as an aim.

Influence of research in science curriculum development

Furthermore, the literature talks about the importance of research and evidence in informing the development of the curriculum and textbooks (especially in China and Estonia). Experts, such as researchers and education specialists, also support curriculum development. For instance, in China, professional scientists play a part in curriculum development (Yao & Guo, 2018) and in Estonia, the Ministry of Education and Research has been said to support science-based policy making, is involved in researching, analysing and evaluating the educational landscape and commissions studies from experts and researchers (Kori, 2022). In other jurisdictions, such as Macao, the literature revealed that research projects investigating science education have also occurred. Wei (2019) states that in Macao, not many academics have been interested in investigating science education and issues around teaching science, thus existing research does not address the issues found in science curriculum and teaching.

High quality teacher training and professional development

Another common theme observed is the emphasis placed on professional development for teachers in jurisdictions like Estonia and Japan, as well as high entry requirements to enter teaching courses in China, Estonia and Japan. Tonga et al. (2019) suggests that all of the jurisdictions investigated appear to have a strong professional development system for trainee and in-service teachers. Although Japan, China, Estonia and Singapore have differences in their teacher education, considering their various approaches to teacher training, admission requirements, induction of graduates and in-service teacher education "based on specific needs, demographics, philosophies and features" is important when considering their PISA success (p. 13). Tonga et al. further states that "teacher training, experience, in-service education and PD are emphasised and updated by considering teacher needs and reflecting on outcomes, such the PISA results (OECD, 2018)" (as cited in Tonga et al., 2019, p. 13). They also state that a common theme across these high achievers is "the availability of comprehensive and high-quality university education and access to the teaching profession is via an admission process… " as well as the requirements that novice teachers are qualified to at least undergraduate level. In addition, some of these jurisdictions have a comprehensive admission process into the teaching profession, an in-service induction which considers the characteristics of the community, an in-service mentoring system, economic support and incentives to encourage teachers to engage in further study, as well as a mandatory in-service training" (p. 13). This indicates that teaching as a profession and continued professional development opportunities for teachers are highly valued in these high performing jurisdictions.

Opportunities for learning about science outside of school

Another common theme concerns science opportunities outside of school. The literature mentioned that Singapore, Macao and Estonia offer additional opportunities available to students to increase their awareness, understanding and engagement in science. This includes various trips, exhibitions and programmes run by universities and the government (e.g., Lee, 2018; Kori, 2022). There were mentions of additional science opportunities in China, but as China includes many different regions, it is unclear if such opportunities are available in all regions to the same extent.

Pedagogy and students' reported experiences

Lau and Lam (2017) looked at the 2015 PISA data from 10 high performing jurisdictions (Singapore, Japan, Estonia, Taipei, Finland, Macao, Canada, Hong Kong, China and Korea) and suggested that there are some commonalities between the counties. For instance, teachers tend to spend a substantial amount of class time in explaining scientific concepts, mixed with class discussion which includes opportunities for learners to express their ideas. A fair amount of practical work is conducted, including investigations involving the design of experiments. The exceptions are Japan and Korea which have remarkably less direct teaching, class discussion, and opportunities for students to express their ideas. The study also reported that teachers gave students little feedback, scored below the OECD average for teacher-directed instruction, and scored low on enquiry-based instruction. Japan stood out from other HPJs in that students reported that they did not engage in much whole-class discussion. "These findings support that good science performance is a result of the teaching that is highly content-focused (Korsnakova, McCrae, & Bybee, 2009; Thomson, 2009)" (as cited in Lau & Lam, 2017, p. 2144). This suggests a slight discrepancy between Japan and other HPJ and makes drawing broad conclusions about these jurisdictions' education systems performance difficult. It also poses questions of why does Japan perform so well in PISA, considering that the classroom pedagogy seems to be slightly different to the other HPJs? We need to maintain caution in assuming that teaching and classroom pedagogy are the same in all schools and classrooms of these high performing jurisdictions when interpreting the findings from studies like this one. The study also analysed data from the 2015 PISA study rather than the most recent 2018 study, therefore the landscape of each jurisdiction could be slightly different now. Such studies may offer an interesting insight into various jurisdictions' education systems, but it is important to consider that it may not paint a holistic picture of what an educational system in a jurisdiction is like and why a jurisdiction performs well in international tests. Other factors, such as a jurisdiction's culture and history may also contribute to its performance.

Distribution of types of knowledge in curriculum documents

Another interesting finding concerns features of curricula of certain HPJs. Wei and Ou (2019) analysed the education systems and junior high school science curriculum standards of Mainland China, Taiwan, Hong Kong and Macao using revised Bloom's taxonomy. They found similarities in distribution of types of knowledge in curriculum documents for Macao and mainland China. The analysis showed that Macao and China tended to emphasise lower levels of cognitive processing, with focus on memory of factual and conceptual knowledge (at the “remember” level of Bloom’s taxonomy) rather than meta-cognitive knowledge (self-knowledge and awareness of knowledge, e.g., knowing the cognitive demands of tasks). There was a far greater proportion of the learning objectives of low-level cognitive processes compared to high-level cognitive processes. The finding that Macao and China pay more attention to the lower-level cognitive processes (e.g., remembering) could be considered surprising in light of their high PISA performance if PISA items require high level cognitive processes (e.g., evaluating) rather than low level processes. However, it is beyond the scope of this report to investigate the nature of science items in PISA in detail. Wei and Ou (2019) state that international assessments like PISA “suggest that education should include higher levels of cognitive learning” (p. 1472) and the literature indicates that “paying attention to the higher-level cognitive processes is a good way to develop students’ critical thinking ability” (p. 1472). As mentioned in the ‘Scientific literacy in PISA’ section of this report, scientific literacy in PISA is assessed through contexts, knowledge and competencies (e.g., evaluating and designing scientific enquiry). It requires “knowledge of common procedures and practices associated with scientific enquiry and how these enable science to advance” (OECD, 2019a, p. 98), but its definition appears to emphasise skills, such as application, analysis, interpretation, and evaluation, in addition to possessing knowledge. At this very quick glance, it appears that the PISA assessment may require some higher-level skills (e.g., analysis) in addition to lower ones (e.g., remembering). However, it is unclear how many questions in the whole assessment focus on higher level cognitive skills and how many on lower-level cognitive processes. To fully investigate what levels of processing PISA items require, is beyond the scope of this report. This poses questions around how we can explain the high performance of China and Macao if their junior high school curriculum standards may emphasise factual and conceptual knowledge rather than the higher-level cognitive skills. Do they tend to perform higher on the elements of PISA that assess knowledge rather than the higher order cognitive processes? Lau and Lam (2017) propose just that, as in their study, they found that Macao and China performed better in areas connected to science content – *explaining phenomena scientifically* (EP) and *content knowledge* (CK).

Considering performance of these jurisdictions on certain components of the science assessment in PISA, Lau and Lam (2017)’s analysis of the 2015 science PISA data found that Singapore performed the best in all areas (*explaining phenomena scientifically, evaluate and design scientific enquiry, interpret data and evidence scientifically, content knowledge* and *procedural and epistemic knowledge*, closely followed by Japan. In contrast China and Macao appeared to perform better in aspects linked with science contents, such as *explaining phenomena scientifically* and *content knowledge*. The authors suggest that such differences in performance in different areas may “reflect the different emphases of science education of a region amongst science content, scientific inquiry and the nature of science. Singapore and Japan are equally good at all areas” (p. 2135).

The importance and influence of culture on education

This theme was explored in the general education section for four of the five HPJs: China, Singapore, Macao and Estonia. It is clear that we should not take countries’ performance on international assessments without considering their history, culture and socio-cultural factors, as these often shape education and curricula. This will be explored in greater detail in the Considerations section.

Although the above draws useful lessons from comparisons between the curricula and education systems of HPJ, further comments on each jurisdiction's curriculum standards and curriculum document contents cannot be made. This would require expertise in science education and teaching, as well as good understanding of the science curriculum documents across primary and secondary education in all five jurisdictions.

Centralisation of education

Whether a jurisdiction has a centralised education system and if/how this could impact on its performance is a very complex question. The review of literature conducted showed that mainland China, Singapore and Japan appear to have more centralised education systems in comparison to Macao (China). It is unclear to what extent Estonia has a centralised system, as schools appear to have a national curriculum, but also the autonomy to use it to develop their own school curricula (NCEE, n.d.a) and some writers report great levels of autonomy available to schools and teachers (e.g., Tire, 2021). It therefore appears that there may be variations in the extent to which educational systems are 'centralised' and 'de-centralised'. Furthermore, Macao has a highly de-centralised system and yet was the 3rd top performing jurisdiction in the science assessment of the 2018 PISA. It is beyond the scope of this report to unpick if (de)/centralisation of education systems contributes to high performance in the PISA assessment. This report intends only to summarise and present common themes that came out from inspecting existing literature. Additionally, each jurisdiction may define centralisation differently, and different elements of its education system may be considered to be more or less centralised (e.g., teaching approaches, the written curriculum, textbooks, professional development). Therefore, caution must be maintained when considering what 'centralisation' is.

It is crucial to consider all aspects reported in this report, such as teacher training and development or centralisation, in the context of each jurisdiction's social, economic, historical and political landscape.

Differences between the jurisdictions

Despite the identified commonalities, there are variations within jurisdictions and evidence is mixed, for instance with regards to inquiry-based teaching. The literature review has also brought up some noticeable differences in the education systems and curricula that are worth mentioning. For instance, Macao has a highly de-centralised education system, with a large proportion of private schools, which do not have to adhere to the curriculum. Schools and teachers also appear to have more autonomy, although the literature indicates that attempts have been made at centralising the system more. Macao's education and textbook market is also heavily influenced by other jurisdictions such as China and Portugal. It is also one of the less established education systems after gaining its sovereignty from Portugal in the late 1990s. However, another noticeable difference worth mentioning is the emphasis that Estonia places on access to high quality education for all students (Tire, 2021) and the help that is given to students from low socio-economic backgrounds. This is supported by the findings that there is a large proportion of students from disadvantaged backgrounds who perform highly in the PISA assessments (Tire, 2021), suggesting that social class may not create a division in the academic achievement of Estonian students. However, it is not clear how these idiosyncrasies amongst the five HPJs influence performance in PISA, if at all.

Limitations

Although this literature review highlighted some interesting issues, it is important to acknowledge some of the limitations faced. First of all, it proved difficult to find relevant literature (less than a decade old, focused on science education and curriculum) for some jurisdictions, such as Estonia and Japan. It may be that the literature exists but is written in the jurisdiction's own language or other (non-English) languages. The literature that was found and investigated for Estonia tended to focus on the general education system rather than science education. This may create difficulties in painting a holistic and accurate picture of science education and curriculum in Estonia. Additionally, this review focused on the educational landscape in the five HPJs in the last decade (with some exceptions). Although this helped to narrow down the focus, it does not allow for an in-depth investigation of how each jurisdiction's history, educational changes, policies and culture have impacted on their current system. Although the literature review attempted to use the latest available research, some research presented may be slightly out of date, especially if it is not based on the latest PISA data or if the jurisdiction has experienced educational reform and policy changes since the research was published.

It is also important to remember that a mixture of sources was used in this literature review, including research articles, websites (e.g., NCEE, TIMS & PIRLS International Study Center) and blogs, especially if there was no research evidence or official governmental websites to support ideas.

Furthermore, this review presents a range of factors which could contribute to high performance of some jurisdictions, but other important factors will most likely, which have not been accounted for, such as attitudes towards science learning or parental support/attitudes. For instance, Tire (2021) states that Estonians are self-critical by nature, which may be one of the reasons for their "driving force for improvement" (p. 118). Although some curricula mention attitudes (e.g., Tan et al., 2016; Wang et al., 2019, see Appendices A-E), this review did not investigate how students' attitudes, parents' attitudes or other interpersonal factors could contribute to the performance of HPJs or how attitudes feature in each nation's history. Furthermore, some of the emerged themes are very complex in nature and may not be connected to high performance in a direct, straight-forward way (e.g., Lau & Lam, 2017).

Considerations

In addition to the similarities and differences identified from the literature, there are also some important aspects that need to be considered when attempting to answer the research question of this paper, namely – what can we learn from high performing jurisdictions?

Firstly, it is vital to recognise that each jurisdiction's history and culture contributes to its education system and thus its performance in international assessments like PISA. Oates (2013) and Deng and Gopinathan (2016) both warn against "'uninformed policy borrowing'" (p. 5), whereby individuals look to other jurisdictions, often in the East, for educational policies and ideas that are then used to enhance the performance of their own educational systems (Sellar & Lingard, 2013, as cited in Deng & Gopinathan, 2016). They argue that it is important to understand the history and institutional context of a system to fully appreciate their education and what can be learn from their system. They also propose that an “over preoccupation with PISA and ranking leads to missing out on the nature and purposes of education broadly construed” (p. 5). Each jurisdiction is different, and policies or practices that work well in one may not necessarily work well in another. Lau and Lam (2017) argue that “caution is needed to attribute the top performance of these regions to particular teaching practices, which are further attributed to particular cultural and social values. There is a host of factors at play other than teaching practices in affecting the educational outcomes of a region, such as demographics, school system, education policy and teacher training” (p. 2145). In support of this, DeBoer (2011, cited in Henno & Reiska, 2013) argues that each jurisdiction has its own unique educational history and values that may impact on their students’ science learning, suggesting between jurisdiction differences. This report also highlighted this issue, as although commonalities between jurisdictions were seen in the literature, variations and discrepancies were also found both between and within jurisdictions (for instance, with regards to the extent to which inquiry learning and approaches are used, and what pedagogies may be employed by teachers). Literature can give some initial insight into these HPJs, but it cannot build a holistic picture of what happens across each jurisdiction, in each school and in every classroom. Elliott (2014) also warns against confusing cause and effect, specifically when regions look to borrow successful policies of high performing jurisdictions and adopt them to enhance own educational performance. She highlights that elements which can be present in multiple high performing jurisdictions are not always necessarily the cause of their strong performance. Furthermore, Oates (2013) suggests that certain control factors which can be helpful in comparing educational systems (such as countries’ policy arrangements, pedagogies, professional development or curriculum content have complex relations), may be difficult to unpick (see para 4 in the Introduction section).

It is also important to consider that despite high performance, many jurisdictions are continuously reforming and adapting their curriculum, practices, and are aware that their own educational systems have limitations that need to be addressed. For instance, Nakamichi and Katayama (2018) make recommendations for improving the science education in Japan, including updating teaching materials and laboratory equipment, as well as providing in-service teachers with more up-to-date knowledge of their subject. This indicates that no jurisdiction has an ideal science curriculum or education model, and that even high performing jurisdictions are aware of own issues and challenges that need to be addressed.

Conclusions

In conclusion, this report gives insight into mainland China, Macao, Singapore, Japan and Estonia - jurisdictions that were the top five science performers in the 2018 PISA assessment. Going back to the research question of this study - what can we learn from these high performing jurisdictions?

This report highlights that building a whole picture of a jurisdiction’s educational performance is a complex endeavour. There may be differences between the written curriculum and what is enacted in classrooms, creating between- and within-jurisdiction discrepancies, and making conclusions difficult. Furthermore, each jurisdiction has its own history and cultural background, which could impact on its current educational policies and practices. This cautions against uninformed policy borrowing or as Lau (2014) calls it – transplanting "success formula" from one jurisdiction to another. This is supported by Oates (2013), who states that "we should use international comparisons to understand how different aspects of the system are subject to control and development, rather than simply engage in crude 'policy borrowing'" (p. 3).

When investigating a jurisdiction's science education or performance in international assessments, such as PISA, the themes that have emerged from the literature may offer some guidance as to what elements may be worth considering. For instance, it may be useful to consider teacher training and development (Tonga et al., 2019), the content of curriculum documents and the role that scientific literacy plays in the curriculum (e.g., Tan et al., 2016; Wang et al., 2019; Wei, 2019), the influence of research on the development of (science) curricula (e.g, Kori, 2022; Ma, 2016; Tan et al., 2016; Yao & Gup, 2018), pedagogy and students' experiences (e.g, Deng & Gopinathan, 2016; Lau & Lam, 2017; Tan et al., 2016; Wei, 2016), and opportunities for learning science outside the classroom (e.g., Kori, 2022; Lee, 2018; OECD, 2016b). However, this report did not establish if any of these factors contributed to the high performance of the five jurisdictions of interest in the 2018 science assessment in PISA, or if any specific elements found in these factors could contribute to high performance (e.g., specific teaching pedagogies). It is vital that factors are considered in the context of each jurisdiction's history, socio-economic and cultural climate, and practices at classroom level, as each jurisdiction is different and what may work in one may not work in another. Simply 'implanting' policies or practices from one jurisdiction to another should be avoided (Lau & Lam, 2017). Furthermore, there are between- and within-jurisdiction/school/classroom differences that exist, which may not be captured adequately when trying to attribute high performance to specific factors.

Although this report comments on the contents of curricula, it is crucial to note that the information was gained from secondary sources, and not from original individual curriculum documents. To learn more about science curriculum content, objectives and standards of these jurisdictions, subject experts would need to examine relevant science curriculum documents. But caution should be maintained against drawing broad conclusions about high performance based on documentary analysis alone, without considering other factors, such as each jurisdiction's history, socio-cultural aspects, classroom practices, or teachers' and students' experiences. This shows that unpicking a jurisdiction's educational performance is a complex task, requiring expertise and knowledge of the subject in question, the written and enacted curriculum, and socio-cultural factors of each jurisdiction. Even then, questions arise about whether the findings can be applied to all students, classrooms, teachers and schools.

Lau and Lam's (2017) comment made in respect to their findings also resonates with the research question of this report - "to conclude, there is no single success formula for science education as shown by the findings of this study" (p. 2146).

References

Abumiya, M. I. (2012). *Upper secondary education in Japan.* https://www.nier.go.jp/English/educationjapan/pdf/201209SE.pdf

Albritton, C. C. (n.d.). Earth sciences. In *Britannica*. https://www.britannica.com/science/Earth-sciences

Anderson, L. W. & Krathwohl, D. R., Airasian, P.W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2001). (Eds.), *A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy of educational objectives*. Allyn & Bacon.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Springer Netherlands.

Bjork, C. (2009). Local implementation of Japan's Integrated Studied Reform: A preliminary analysis of efforts to decentralise the curriculum. *Comparative Education, 45*(1), 23-44.

Cambridge Assessment International Education. (n.d.) *Getting started with active learning.* https://www.cambridge-community.org.uk/professional-development/gswal/index.html

Cave, P. (2001). Educational reform in Japan in the 1990s: 'Individuality' and other uncertainties. *Comparative Education, 37*(2), 173-191. https://www.jstor.org/stable/3099656

CIA. (n.d.a). *China.* The world factbook. https://www.cia.gov/the-world-factbook/jurisdictions/china/#introduction

CIA. (n.d.b). *Macau.* The world factbook. https://www.cia.gov/the-world-factbook/countries/macau/

CIA. (n.d.c). *Singapore.* The world factbook. https://www.cia.gov/the-world-factbook/jurisdictions/singapore/

Crehan, L. (2016, October 11). Teacher-led professional development in Singapore. https://lucycrehan.com/teacher-led-professional-development-in-singapore/

Cui, Y., & Zhu, Y. (2014, June 12-14). *Curriculum reforms in China: History and the present day* [Paper presentation]. Revue internationale d'éducation de Sèvres, Education in Asia 2014: What global issues? Online. https://journals.openedition.org/ries/3846

Deng, Z., & Gopinathan, S. (2016). PISA and high-performing education systems: Explaining Singapore's education success, *Comparative Education, 52*(4), 449-472. 10.1080/03050068.2016.1219535

Department for Education. (2015). *Biology, chemistry and physics: GCSE subject content.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/800342/GCSE_single_science_updated_May_2019.pdf

Department for Education & National Foundation for Educational Research. (December 2019). *Achievement of 15-year-olds in England: PISA 2018 results (Executive Summary).* Department for Education. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904419/PISA_2018_England_Exec_summary.pdf

Ding, B. (2015). Science education in mainland China. In R. Gunstone (Ed.), *Encyclopedia of Science Education* (pp. 882-889). Springer Netherlands.

Dixon, L. Q. (2005). The bilingual education policy in Singapore: An analysis of its sociohistocial roots and current academic outcomes. *International Journal of Bilingual Education and Bilingualism, 8*(1), 25-47. https://www.tandfonline.com/doi/abs/10.1080/jBEB.v8.i1.pg25

Doig, B. & Groves, S. (2011). Japanese lesson study: Teacher professional development through communities of inquiry. *Mathematics Teacher Education and Development, 13*(1), 77-93. https://files.eric.ed.gov/fulltext/EJ960950.pdf

The Editors of Encyclopaedia Britannica. (n.d.). *Macau.* Britannica. https://www.britannica.com/place/Macau-administrative-region-China

Elliott, G. (2014). Method in our madness? The advantages and limitations of mapping other jurisdictions' educational policy. *Research Matters: a Cambridge Assessment publication, 17*, 24-28. http://www.cambridgeassessment.org.uk/Images/164660-research-matters-17-january-2014.pdf

Eriksen Translations. (n.d.). *Simplified vs. Traditional Chinese.* https://eriksen.com/language/simplified-vs-traditional-chinese/#:~:text=Simplified%20Chinese%20is%20typically%20used,Traditional%20Chinese%20is%20the%20norm.

Eurydice. (n.d.a). *Estonia: Organisation and governance.* https://eacea.ec.europa.eu/national-policies/eurydice/content/organisation-and-governance-24_en

Eurydice. (n.d.b). *Estonia: Teaching and learning in single-structure education.* https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-and-learning-single-structure-education-10_en

Gao, X. (2017, December 24). The improvement of education in Macau. *The borgen project.* https://borgenproject.org/education-in-macau/

Ginshima, F., & Matsubara, K. (n.d.). *Japan: Overview of education system.* TIMSS & PIRLS International Study Center. http://timssandpirls.bc.edu/timss2015/encyclopedia/jurisdictions/japan/

Gruijters, R. J. (2020, February 18). How (unrepresentative) are China's stellar PISA results? *Network for International policies and cooperation in education and training.* https://www.norrag.org/how-unrepresentative-are-chinas-stellar-pisa-results-by-rob-j-gruijters/

Halpin, D. (2010). National curriculum reform in China and England: Origins, character and comparison. *Frontiers of Education in China, 5*(2), 258-269.

Henno, I., & Reiska, P. (2013). Impact of the socio-cultural context on student science performance and attitudes: The case study of Estonia. *Journal of Baltic Science Education, 12*(4), 465-481.

Hiroshima University. (2003). *Active learning.* https://www.hiroshima-u.ac.jp/en/sgu/page03_03

Impel. (2019). *Education system.* https://impeloverseas.com/study-abroad/study-in-singapore/education-system/

Isozaki, T. (2018). Science teacher education in Japan: Past, present and future. *Asia Pacific Science Education, 4*(1), 1-14. 10.1186/s41029-018-0027-2

Jerrim, J. (2022). The benefits of meeting key grade thresholds in high-stakes examinations. New evidence from England. *British Journal of Educational Studies.* https://doi.org/10.1080/00071005.2022.2033692

Jnto. (n.d.). *Japanese educational system*. https://education.jnto.go.jp/en/school-in-japan/japanese-education-system/

Kori, K. (2022). Science education in Estonia. In R. Huang, B. Xin, A. Tlili, F. Yang, X. Zhang, L. Zhu, & M. Jemni (Eds.), *Science education in countries along the belt & road: Future insights and new requirements* (pp. 385-398). Springer. https://link.springer.com/chapter/10.1007/978-981-16-6955-2_23

Kumano, Y. (2009). The systemic reform of science education in Japan – present and future. In N. Pavlovna Tarasova (Ed.), *Quality of human resources: Education* (Vol. 2). United Nations Education, Scientific and Cultural Organisation.

Lau, K. C. (2014). The science education of the East Asian regions – what we can learn from PISA. *Asia-Pacific Forum on Science Learning and Teaching, 15*(2), p. 1-18.

Lau, K. C., & Lam, R. Y.-P. (2017). Instructional practices and science performance of 10 top-performing regions in PISA 2015. *International Journal of Science Education, 39*(15), 2128-2149. 10.1080/09500693.2017.1387947

Lee, Y-J. (2018). Primary science education in Singapore. In Y-J. Lee & J. Tan (Eds.), *Primary science education in East Asia* (Vol. 47, pp. 157-176). Springer International Publishing. http://link.springer.com/10.1007/978-3-319-97167-4_7

Lee, C. L., & Phua, C. P. (2020). Singapore bilingual education: One policy, many interpretations. *Journal of Asian Pacific Communication, 30*(1-2), 90-114. https://doi.org/10.1075/japc.00046.lee

Liu, X.-F. (2017). Science education reform policies. In L. L. Liang, X. Liu, & G. W. Fulmer (Eds.), *Chinese science education in the 21st century: Policy, practice, and research* (pp. 1–4). Springer.

Lo You Chun, J. (2005). Curriculum Reform. In M. Bray & R. Koo (Eds*.), Education and society in Hong Kong and Macao: Comparative perspectives on continuity and change* (pp. 161-174). Springer Netherlands. https://doi.org/10.1007/1-4020-4449-6_11

Loogma, K. (n.d.). *Estonian Education Forum* [PowerPoint slides]. Eunec. http://www.eunec.eu/sites/www.eunec.eu/files/event/attachments/presentation_loogma.pdf

Ma, M. (2016). The development and characteristics of elementary science curriculum in China. *US-China education review, 6*(11), 642-649. 10.17265/2161-623X/2016.11.003

Mariel, P., Sanko, N., & Vega-Bayo. (2021). The effect of the Free High School Tuition law on upper-secondary school choice in Japan. *Studies in Educational Evaluation, 70,* 101065. https://doi.org/10.1016/j.stueduc.2021.101065

MEXT. (n.d.). *Part I: Issues and perspectives of elementary and secondary education: Chapter 2: Measures for the enrichment of elementary and secondary education: 7. Response to internationalization and information oriented society (1) Response to internationalization.* Ministry of Education, Culture, Sports, Science and Technology. https://www.mext.go.jp/b_menu/hakusho/html/hpae198901/hpae198901_2_026.html

Ministry of Education. (2001). *The development of education: National report of Estonia*. International Bureau of Education. http://www.ibe.unesco.org/fileadmin/user_upload/archive/International/ICE/natrap/Estonia.pdf

Ministry of Education. (2019). *Supporting our students through the years – evolution of streaming in secondary schools.* https://www.moe.gov.sg/microsites/psle-fsbb/assets/infographics/full-subject-based-banding/Evolution-of-Streaming.pdf

Ministry of Education. (n.d.). *Normal (academic) course for secondary school.* https://www.moe.gov.sg/secondary/courses/normal-academic

Nakamichi, T., & Katayama, N. (2018). Biology education in upper secondary schools at present in Japan. *Asian Journal of Biology Education, 10*, 7-16.

National Institute for School Leadership. (2019). *Singapore's career ladder system.* National Center on Education and the Economy. https://www.ncsl.org/Portals/1/Documents/educ/NISLSingapore%27sCareerLadderSystem.pdf

NCEE. (n.d.a). *Estonia.* https://ncee.org/jurisdiction/estonia/

NCEE. (n.d.b). *Japan.* https://ncee.org/jurisdiction/japan/

NCEE. (n.d.c). *Singapore.* https://ncee.org/jurisdiction/singapore/

Oates, T. (2013). *Education, assessment and developing a comprehensive qualifications framework.* Cambridge Assessment. https://www.cambridgeassessment.org.uk/images/130106-tim-oates-paper-education-assessment-and-developing-a-comprehensive-qualifications-framework-.pdf

OECD. (2013). *PISA 2012 assessment and analytical framework.* OECD Publishing. https://www.oecd.org/pisa/aboutpisa/PISA%20scales%20for%20pisa-based%20test%20for%20schools.pdf

OECD. (2016a). *Education in China: A snapshot.* https://www.oecd.org/china/Education-in-China-a-snapshot.pdf

OECD. (2016b). *PISA 2015 high performers*: *Singapore.* https://www.oecd.org/pisa/PISA-2015-singapore.pdf

OECD. (2016c). School education in Estonia. In *OECD Reviews of School Resources: Estonia 2016* (pp. 35-68). OECD Publishing. https://www.oecd-ilibrary.org/docserver/9789264251731-5-en.pdf?expires=1657197419&id=id&accname=guest&checksum=4A61468809B083E36603902DFF39F25C

OECD. (2017). What is PISA? In *PISA 2015 Assessment and Analytical Framework: Science, reading, mathematics, financial literacy and collaborative problem solving*. OECD Publishing. https://doi.org/10.1787/9789264281820-2-en

OECD. (2018a). *Education policy in Japan: Building bridges towards 2030.* https://www.oecd.org/education/Japan-BB2030-Highlights.pdf

OECD. (2019a). *PISA 2018 assessment and analytical framework.* OECD Publishing. https://doi.org/10.1787/b25efab8-en.

OECD. (2019b). *PISA 2018 results (Volume I): What students know and can do.* OECD Publishing. https://doi.org/10.1787/5f07c754-en.

Open University. (2019, August 30). *A brief introduction to the Chinese education system.* https://www.open.edu/openlearn/education-development/a-brief-introduction-the-chinese-education-system

Pedaste, M., Mitt, G., & Jürivete, T. (2020). What is the effect of using mobile augmented reality in K12 inquiry-based learning? *Education Sciences, 10*(4), 94. https://doi.org/10.3390/educsci10040094

Pei, W. (2019). Curriculum reform of science in elementary schools in China. *Beijng International Review of Education, 1*(2-3), 573-578. https://doi.org/10.1163/25902539-00102007

Phillips, D., & Ochs, K. (2004). Researching policy borrowing: Some methodological challenges in comparative education. *British Educational Research Journal, 30*(6), 773-784. 10.

Schleicher, A. (2019). *PISA 2018: Insights and interpretations.* OECD. https://eric.ed.gov/?id=ED601150

Schneider, M. (2019, December 10). Schneider: The strange case of ‘China’ and its top PISA rankings – how cherry-picking regions to take part skews its high scores. The 74. https://www.the74million.org/article/schneider-the-strange-case-of-china-and-its-top-pisa-rankings-how-cherry-picking-regions-to-take-part-skews-its-high-scores/

Scholaro. (n.d.a). *Education system in China.* https://www.scholaro.com/db/countries/china/education-system

Scholaro. (n.d.b). *Education system in Macau.* https://www.scholaro.com/pro/Countries/Macau/Education-System

Tan, K. C. D., Teo, T. W., & Poon, C-L. (2016). Singapore science education. In M-H. Chiu (Ed.), *Science education research and practice in Asia: Challenges and opportunities* (pp. 155-174). Springer Singapore. https://doi.org/10.1007/978-981-10-0847-4_9

Tang, H., Qui, C., Meng, L., Li, Y., & Zhang, J. (2020). Factors predicting inquiry-based teaching in science across one belt one road jurisdictions and regions: A multilevel analysis. *SAGE Open,* 1-12. 10.1177/2158244020932511

TIMSS & PIRLS International Study Center. (n.d.). *TIMSS 2015 Encyclopedia: Japan.* IEA. http://timssandpirls.bc.edu/timss2015/encyclopedia/jurisdictions/japan/the-science-curriculum-in-primary-and-lower-secondary-grades/

Tire, G. (2021). Estonia: A positive PISA experience. In N. Crato (Ed.), *Improving a jurisdiction's education* (pp. 101-120). Springer International Publishing. http://link.springer.com/10.1007/978-3-030-59031-4_5

Tonga, F. E., Eryiğit, S., Yalçın, F., & Erden, F. (2019). Professional development of teachers in PISA achiever jurisdictions: Finland, Estonia, Japan, Singapore and China. *Professional Development in Education, 48*(1), p. 88-104. https://doi.org/10.1080/19415257.2019.1689521

Wang, Y., Lavonen, J., & Tirri, K. (2019). An assessment of how scientific literacy-related aims are actualised in the National Primary Science curricula in China and Finland. *International Journal of Science Education, 41*(11), 1435-1456. https://doi.org/10.1080/09500693.2019.1612120

Wei, B. (2016). School science teaching and learning in Macau: Problems and challenges. In M-H. Chiu (Ed.), *Science education research and practice in Asia: Challenges and opportunities* (pp. 55-70). Springer

Wei, B. (2019). Science teacher education in Macau: A critical review. *Asia-Pacific Science Education, 5*(1), 1-13. 10.1186/s41029-019-0036-9

Wei, B., Lin, J., Chen, S., & Chen, Y. (2020). Integrating 21st century competencies into a K-12 curriculum reform in Macau. *Asia Pacific Journal of Education.* 10.1080/02188791.2020.1824893

Wei, B., & Ou, Y. (2019). A comparative analysis of junior high school science curriculum standards in mainland China, Taiwan, Hong Kong, and Macao: Based on revised Bloom's taxonomy. *International Journal of Science and Mathematics Education, 17*, 1459-1474.

Wheeler, J. (2019). Macau or Macao? A case study in the fluidity of how languages interact in Macau SAR. *Journal of English as an International Language, 14*(1), 73-91. https://eric.ed.gov/?id=EJ1244666 s

Wise. (2017, July 18). *The Singapore education system: An overview.* https://wise.com/gb/blog/singaporean-education-overview

WorldAtlas. (n.d.a). *Provinces and administrative divisions of China.* https://www.worldatlas.com/articles/provinces-and-administrative-divisions-of-china.html

WorldAtlas. (n.d.b). *What languages are spoken in China?* https://www.worldatlas.com/articles/what-languages-are-spoken-in-china.html

Worlddata. (n.d.). *Macao.* https://www.worlddata.info/asia/macao/index.php

Worldpopulationreview. (n.d.). *Macau population 2022.* https://worldpopulationreview.com/country-territories/macau-population

Yang, M., Cooc, N., & Sheng, L. (2017). An investigation of cross-linguistic transfer between Chinese and English: A meta-analysis. *Asian-Pacific Journal of Second and Foreign Language Education, 2*(15). https://sfleducation.springeropen.com/articles/10.1186/s40862-017-0036-9

Yao, J-X., & Guo, Y-Y. (2018). Core competences and scientific literacy: The recent reform of the school science curriculum in China. *International Journal of Science Education, 40*(15), 1913-1933.

Appendices

Appendix A

Summary of literature around science education and curriculum in mainland China (presented in ascending order)

Research	**Detail**
Halpin (2010)	More space for teacher-discretion in selecting curriculum resources, developing schemes of study, and greater priority to school-based curriculum development and experimentation at school level, "staircase" model of curriculum implementation (central state, provincial educational administrations, schools/teachers).
Lau (2014)	Integrated PISA results from 2006 to 2012. Although the study looked at Shanghai, some analyses (e.g., looking at the associations between pedagogies and students' enjoyment of science) did not include Shanghai as the jurisdiction joined PISA after 2006 thus data was not available. Based on the 2012 data, found that Shanghai had a high proportion of top performers (those at levels 5 and 6). Chinese students were motivated intrinsically and extrinsically compared with Japanese students. Low self-concept was common to students in all East Asian jurisdictions. Class size in Shanghai appeared to be large, with high proportion of classes exceeding 36 students (data from language classes).
Ma (2016)	Science curriculum and textbooks are based on research, curriculum pays attention to science concepts and practices, science readings are important in the curriculum.
Lau & Lam (2017)	Analysed ten top-performing jurisdictions in PISA 2015 on their science scores and compared these jurisdictions' instructional/teaching practices to find out how they related to their science performance. Found that China showed great disparity between their high and low performing students. China (and Macao) performed well in areas linked to science contents: *explaining phenomena scientifically (EP)* and *content knowledge (CK).* However, China (and Japan) were found to be below the OECD average for enquiry-based instruction. Although Singapore and Macao tended to do more experiments than the OECD average, only China engaged students in designing experiments (a key feature of scientific investigation). Authors concluded that *interactive application* (a newly revised construct of enquiry-based instruction focused on teaching science by applying it to everyday situations through interacting with student ideas) saw the most score gains in China, but the least in Japan and Singapore.
Yao & Guo (2018)	Suggest that researchers, scientists, and science educators appear to have a dominant voice in China's science education curriculum reforms. Science curriculum has seen many reforms over the last few years. For instance, *Compulsory primary school science curriculum standards* were revised, and science teaching started earlier (in grade 1) compared to previously, when it happened in grade 3, leading some to view the revised science curriculum as more coherent and consistent. The curriculum also emphasises 'scientific spirit', there is greater emphasis on physics in senior high school, core competencies have been developed, and attempts have been made to link curriculum standards with assessment. In senior high schools, science curricula have also undergone revisions, including: an increased proportion of elective modules and the rearrangement of the proportion of compulsory credits. The primary science curriculum adopted a four-dimensional goal system focusing on *scientific knowledge, scientific inquiry, scientific attitude* and *science, technology, society and environment*. In senior high school physics curriculum,

	the following four core competencies have been adopted: *big idea of physics, scientific thinking, scientific inquiry* and *scientific attitude and responsibility*, which organise the physics standards. Chemistry and biology curricula also have core competencies attached. The authors investigated the characteristics of China's new science curriculum standards at primary and secondary levels using historical retrospection and text analysis. They found that the development of scientific literacy has been a key goal for China and various documents supporting this have been developed, including *The Outline of Action Plan for Scientific Literacy for All (2006-2010-2020).* They identified core competencies for physics, chemistry and biology. They also identified three curricular changes that are significant for science education in China: re-organisation of the course structure, development of goal systems and linking curriculum standards with assessment. They also reported greater emphasis on teaching/learning physics in senior high school compared to biology or chemistry. This may be because physics is difficult for students and requires more learning time, and because it is seen as the key foundation for the development of scientific literacy. The recent reform attempted to link curriculum standards with assessment, with the aim of achieving coherence and consistency.
Pei (2019)	The 2017 curriculum reforms reflect four strategies: increasing the length of time that students study science (from grade 3 to 1), integrating engineering and technology into science, design of curriculum based on the idea of learning progressions, using big concepts to guide teaching contents. Inquiry-based activities are encouraged.
Wei & Ou (2019)	Explored similarities and differences among four Chinese regions: mainland China, Taiwan, Hong Kong and Macao, in relation to their science curriculum standards using Revised Bloom's Taxonomy. Used sections of the following junior high school science curriculum documents: the 2011 *Compulsory Science Curriculum Standards* (grades 7-9) (China), and the 2017 *Requirements of Basic Academic Attainments for Junior Secondary and Natural Science* (Macao). Found a specific distribution of types of knowledge in curriculum documents for Macao and China, starting with the most prominent: conceptual knowledge (60%), followed by procedural knowledge, factual knowledge. Meta-cognitive knowledge did not feature in China (and Macao), suggesting that the curriculum documents in junior high school attach little importance to meta-cognitive knowledge. After applying the Revised Bloom's Taxonomy to the curriculum documents, the authors concluded that China (and Macao) "have low cognitive requirements and emphasize the memory of knowledge in their junior high school science curricula" (p. 1468). "Remember" and "understand" levels featured the most in the documents, suggesting that the learning requirements for low-level cognitive processes are higher than those for high-level processes. Suggested that mainland China and Macao "stress conceptual knowledge at the remember level" instead of stressing the "understand level or higher-level cognitive processes", which is not completely compatible with the emphasis on developing students' scientific literacy and explaining phenomena scientifically as suggested in their curriculum documents or the PISA 2015 assessment framework.
Tonga et al. (2019)	In China (Japan and Estonia), teacher candidates must successfully complete two assessments: a university entrance exam (which assesses academic achievement in maths, language and science) and a practice exam (which looks at teaching abilities,

	interpersonal skills and communication skills) (Mete, 2013 as cited in Tonga et al., 2019).
Wang et al. (2019)	Compared the Chinese and Finnish primary science curricula. Found that the "structure and basic content of the Chinese primary school curriculum (CH-PSC) was similar to the Finnish" (p. 1445) but that the "core task of the Chinese curriculum is to develop scientific literacy" (p. 1452). The CH-PSC gives reasons as to why science is taught at primary level whereas the Finnish curriculum does not. Scientific literacy is outlined as a core task in the CH-PSC and appears in the document 11 times. The CH-PSC also states specific objectives and outlines what students should know or be able to do, thus addressing learning outcomes, for instance "students should know how to design a research plan if they want to engage in scientific enquiry" (CH-PSC, p. 6). The subject content objectives are also different between the two jurisdictions. Content in the CH-PSC is described in general and in concrete terms and offers a list of objectives under subheadings such as 'physical sciences', 'life sciences', Earth and space sciences' and 'technology and engineering' (p. 1447). The CH-PSC appears to mention the topic of 'forces' much more. Furthermore, understanding classic subjects seems to be emphasised, despite the curriculum highlighting enquiry and applying knowledge-based skills. Both curricula cover the three key categories of scientific literacy: scientific competencies, scientific knowledge and attitudes to science, with scientific knowledge being more prominent in terms of quantity. Scientific competencies are mentioned in both curricula and in the CH-PSC they are based on evidence of scientific enquiry. Both curricula include objectives for the development of competencies. An example of scientific competency and knowledge: "with the teacher's guidance, students learn to ask questions by observing and comparing the phenomena in which they are interested" (Objectives of Scientific Enquiry, CH-PSC, p. 7). Compared to the Finnish curriculum, the CH-PSC contains fewer statements on scientific competencies, but more units of scientific knowledge. In terms of competencies, the CH-PSC seems to contain more competencies that focus on 'explaining' and both curricula do not put much emphasis on interpreting as a competency. This suggests that the objectives of the primary science curricula in both jurisdictions may be more focused on students experiencing science, developing an interest in science and mastering basic knowledge and competencies rather than developing high level competencies such as those in the 'inquiry' and 'interpretation' competencies. In the CH-PSC, units related to practice refer to hands-on activities or technology and there is less emphasis on "daily application of scientific knowledge" compared to the Finnish primary science curriculum (p. 1449). In both curricula, the three types of scientific knowledge show a similar pattern of emphasis: content knowledge constitutes that largest part, followed by procedural knowledge and then epistemic knowledge. However, in the CH-PSC, the number of statements on content knowledge is three times greater than the number of statements on procedural knowledge. This could be for two reasons: a) because the CH-PSC is written in a more concrete and detailed way, and b) because the distribution of scientific competencies in each curriculum is different, with the CH-PSC not giving much attention to the 'inquiry' domain, which usually requires procedural and content knowledge, whereas the 'explain' competency (heavily prevalent in the CH-PSC) usually involved applying content knowledge. Both curricula place emphasis on developing interest and positive feelings/attitudes towards science in students. However, quotes from the CH-PSC appeared to

	emphasise the role of students and student performance without explicitly mentioning the teacher's role in meeting objectives, which was different in the Finnish curriculum (see page 1450 for examples). Considering the frequency of learning contexts in topics, the CH-PSC emphasises 'natural resources and technology' and 'environmental quality' more than 'health and disease', 'hazards' or 'frontiers of science and technology' (p. 1451). Both curricula appear to attempt to link content to "concrete personal and local context", e.g., the CH-PSC mentions large topics at global level and links them to the development of earth and humans (example learning context in the CH-PSC: "the material in the primary science curriculum is selected from the students' daily lives and natural phenomena, pp. 2-3" (p. 1451).
Tang et al. (2020)	The 2016 PISA report suggests "how in inquiry-based science education, students are engaged in experimentation and hands-on activities, challenged, and encouraged to develop a conceptual understanding of scientific ideas" (p. 5). Mainland China included inquiry-based teaching in their reform policies and teaching initiatives, for instance, in their curriculum standards for 1-9 grade students in 2001 and 2022 (Xie, 2014, as cited in Tang et al., 2020), but teachers felt it was time-consuming (Jian & Sun, 2015, cited in Tang et al., 2020). Used data from PISA 2015 to assess inquiry-based teaching in high and low performing jurisdictions. Found that the greater the teacher collaboration (e.g., discussions of teaching and learning ideas), the greater the scores on inquiry-based questions in all jurisdictions investigated, including China (and Macao). Teachers' beliefs about inquiry approaches were also positively correlated with inquiry-based teaching, which is consistent with previous research. In China, professional development activities were negatively correlated with inquiry-based teaching.

Appendix B

Summary of literature around science education and curriculum in Macao (presented in ascending order)

Research	Detail
Jennifer (2005)	Macao is short of curriculum development specialists and initially, curriculum development was led by the Education Reform Committee headed by governmental figures. Teachers often develop own teaching materials due to a lack of localised materials. Teachers in Macao rely heavily on textbooks, but textbooks tend to be imported from jurisdictions such as Hong Kong and Portugal. Recent efforts to produce local textbooks have been made. The first local public examination was organised in 1990 by the University of East Asia.
Lau (2014)	Found that students in Macao tended to have greater interest in science, enjoyed learning science and valued science learning from a personal and career perspectives more compared to students from other OECD jurisdictions. Despite this, they had low self-concept in science. Students indicated that they did not spend much time engaged in application, interaction, hands-on-activities or investigation during science lessons. Over 40% of students in Macao took 4 or more hours of science lessons a week. Many students also received out-of-school support, which was seen as a "booster of performance" (p. 13).
Wei (2016)	This paper reported on some elements of science education in primary and secondary science education in Macao using data from an evaluation project commissioned by the DSEJ. Suggests that raising the level of scientific literacy is a key goal of pre-college education and has been used when recommending teaching methods in international influential science education innovations, such as the National Science Education Standards. All schools investigated in this study offered physics, chemistry and biology, but less than ¼ offered integrated science and none offered Earth or Space science. On average, students in each grade of junior secondary school studied science for 4.4 hours per week. At senior secondary school, students were split into science and art streams. In most schools, students in the art stream did not study science courses and those that offered science offered biology courses. Found that students in science streams tend to have 25.4 hours of science per week. Most teachers in private schools produce their own teaching outlines and do not have to follow the science curriculum. School teaching has been influenced by counties like China, as since 1999 many secondary school graduates moved to China for further study and school science curriculum is influenced by university admission tests. Science textbooks are influenced by or imported from other jurisdictions such as the US or UK, and teachers rely heavily on textbooks. Teaching methods tend to be teacher-centred (lecturing, raising questions and demonstrating), students tended to learn in passive ways and laboratory activities did not encourage openness. Students felt positive about science, but decisions around whether to continue with science in senior secondary school or beyond were dependent upon their interest, future career aspirations and own beliefs in ability. With the gambling industry being prominent, students worried about finding science-related jobs.
Lau & Lam (2017)	Macao was shown to have low proportions of the top and bottom-performing students, suggesting fair performances across the student population. Macao (and China) performed well in areas linked to science contents: *explaining phenomena scientifically (EP)* and *content knowledge (CK).* Macao (and Singapore) tended to do more

	experiments than the OECD average, but only China engaged students in designing experiments (a key feature of scientific investigation).
Wei (2019)	Since establishing independence, the Macao SAR Government has attempted to exercise control over education and create new policies towards centralisation. Scientific literacy was set as the key goal of the RBAA for junior and senior secondary schools. Scientific literacy education is seen to be for all students and science education aims to connect science, the contemporary society and students' daily experiences. The scientific inquiry and students' self-regulated learning are the main focus (Wei, 2018a, as cited in Wei, 2019). Three basic curriculum ideas were set up for the RBAAs to achieve scientific literacy-oriented education focused around promoting students' overall development and improving scientific literacy; strengthening the connections between various disciplines; and laying stress on the diversification of teaching methods and actively promoting inquiry learning. Subject content of science for junior secondary schools was selected from four traditional subjects: physics, chemistry, biology and physical geography, thus the four learning areas identified for the RBAA for junior secondary schools were: a) scientific inquiry, b) physical science, c) life science, and d) the earth and space sciences. All were further divided into 12 categories of items. In senior secondary schools, a vision II was suggested for scientific literacy– the subject content was focused on the situations where "science demonstrably plays a role in human affairs" (Roberts, 2011, p. 12, cited in Wei, 2019, p. 7). Thus, the RBAAs for senior secondary schools are constructed in the following four learning areas: a) scientific inquiry, b) history and nature of science, c) environments and resources, and d) modern technology. The learning domains and categories of the RBAAs for junior and senior secondary schools can be seen in Table 3 on p. 7 in Wei (2019). Various initiatives to improve teacher education have emerged. As scientific inquiry is a new component of subject knowledge required from teachers, it may be strange to those who trained in the more traditional science teaching, thus there is a need to further develop their knowledge. A similar challenge for teachers is using emerging STEM-related pedagogies, such as Artificial Intelligence, which are often assessed in science contests. Another challenge comes from the implementation of integrated science, as more junior secondary schools are attempting to replace separate science courses with the integrated science course under the influence of Hong Kong and China. In order to deliver the integrated science curriculum, teachers must update their professional knowledge and go beyond the subject of their expertise.
Wei & Ou (2019)	For more detail see Wei & Ou (2019) in China's science education section
Wei et al (2020)	Analysed the distribution of the 21st century competencies in the curriculum goals of 39 RBAAs across the four educational stages. Looked at 10 competencies grouped into four categories: 1) *ways of thinking* (competencies focused on the cognitive domain), 2) *ways of working* (competencies needed to do a project, e.g., collaboration, communication), 3) *tools for working* (competencies in comprehending or using tools, such as information literacy and ICT literacy) 4) *living in the world* (competencies needed to negotiate the changing world with respect to life, society and culture, such as Citizenship). The distribution of the 21st century competencies across the four stages was similar, with *ways of thinking* being the most prominent and the *tools for working* the least. Within the *ways of thinking* category there are three competencies: creative thinking, critical thinking and learning to learn. In primary, junior secondary and senior secondary school, learning to learn was the most emphasised competency and creative thinking the least (see Wei et al., 2020, Table 3).

	Within the *ways of working* category, two competencies exist: collaboration and communication. Communication was found to be the most prominent competency across the primary, junior and senior secondary stages. Within the *tools for working,* two competencies exist: information literacy and ICT literacy. Information literacy was seen more in the RBAAs across primary-senior secondary education, as phrases such as "obtain or analyse information" were found to appear often in the RBAAs. Within the *living in the world,* three competencies were found: Citizenship, life and career, and personal and social responsibility. Personal and social responsibility had the highest frequency across primary-senior secondary education. Life and career had a high frequency (46.8%) in senior secondary curriculum documents. Researchers then mapped the ten 21st century competencies for subjects in six learning domains at the junior secondary stage. Within the learning domain of interest to this project- the science and technology domain, three competencies appeared the most often: critical thinking (19%), ICT literacy (15.7), and information literacy (15.2%) (see Table 8 in Wei et al., 2020). The authors concluded that different 21st century competencies can be found in different learning domains, and this may be linked to the nature of these subjects.
Tang et al (2020)	Macao started new reform agendas trying to include inquiry-based teaching but have encountered challenges. Found that the greater the teacher collaboration (e.g., discussions of teaching and learning ideas), the greater the scores on inquiry-based questions in all jurisdictions investigated, including Macao. Teachers' beliefs about inquiry approaches were also positively correlated with inquiry-based teaching. At school level, in Macao, the more developed the region in which the school was located, the greater the use of inquiry-based teaching by teachers. Lastly, teachers who had science-specific resources were more likely to adopt inquiry-based teaching more frequently than those who did not.

Appendix C

Summary of literature around science education and curriculum in Singapore (presented in ascending order)

Research	Detail
Lau (2014)	Singapore joined PISA later, thus some analyses of the 2006 data did not include Singapore. There is a high proportion of top performers in science (those achieving levels 5 and 6) and a low proportion of those not achieving scientific literacy (below level 2). There is a high proportion of large class sizes (36 or more students) (data from language classes).
Tan et al. (2016)	"Science as an inquiry" used to implement the science curriculum framework and includes a) knowledge, understanding and application, b) skills and processes, c) ethics and attitudes (p. 159). Developing students' scientific literacy is part of the Ministry of Education's (MoE) framework for the twenty-first century competencies and aims to prepare learners for globalisation and technological advances. The national primary curriculum aims to provide experiences, stimulate curiosity and develop skills needed for scientific inquiry. Lower secondary school science employs a spiral curricular design – revisiting of primary science content and building on knowledge and skills. Scientific Endeavour included in the curriculum. More chemistry content and field trips. Social and moral issues explored through debates or drama. Inquiry-based activities not as prominent in upper secondary science and science is an elective subject. Emphasis on higher education preparation and examinations. Extensive use of ICT. Students interested in science can participate in additional programmes run by the government and universities. Two science-specialist schools offer courses to secondary and pre-university students. Increased research into science education. Changes to teacher development policies.
Deng & Gopinathan (2016)	Post-colonial Singapore saw the implementation of a uniform curriculum (taught in English) replacing the Chinese-Malay-English-based curricula. The new curriculum focused on maths, science, languages, and technical subjects to support industrialisation. The New Education System in 1980 created a two-tier curriculum (students learning English and mother language), a three-track primary system (tracked students into three streams based on end of Primary examinations: *Normal bilingual, Extended bilingual, Monolingual*), and three-tier track secondary system (*Special, Express, Normal)*. Past focus was given to high-stakes examination system, exam performance, private tuition, largely traditional (didactic) classroom practice. Attempts to reform the curriculum to more student-centric and promoting active learning. Initiatives rolled out between 1997-2005 to support a vision of pedagogy promoting higher-order thinking, meaningful use of ICT and interdisciplinary learning. Despite such initiatives, research suggests that classroom pedagogy is still mostly traditional and directed towards curriculum content delivery, examinations, whole-class teaching, mastery of procedures and problem-solving skills and content mastery.
Lau & Lam (2017)	Singapore had the highest proportion of top-performing students and the smallest proportion of low-performing students. The authors concluded that Singapore's science education can support the academically strong and weak students. With regards to competencies and knowledge, Singapore performed specifically well in the areas of *evaluate and design*

	scientific enquiry (ED) and *procedural and epistemic knowledge (PEK)*, which may reflect the emphasis on scientific inquiry. Teaching was found to be more teacher-led, but instruction was found to be more adaptive, meaning it was often adapted to students' needs. Students also reported that teachers gave them individual feedback in class and whole-class discussions were found to be common but were more authoritative and dialogic. Singapore (and Macao) tended to do more experiments than the OECD average, but only China engaged students in designing experiments (a key feature of scientific investigation). *Interactive application* saw the least score gains in Singapore (and Japan).
Lee (2018)	Constant revolution in education. Private tutoring and pressures to perform well in high-stakes assessments are common. Inquiry is the key feature of the primary science curriculum, with the teacher leading the inquiry and students raising questions about science in everyday life. Scientific skills, processes, ethics and attitudes are emphasised in the curriculum. 21^{st} century goals, including scientific literacy (reasoning from evidence and applying knowledge) are some of the key aims of science education. Despite this, some evidence suggests that teacher-led delivery focused on factual knowledge is still most common. The five themes in the 2014 primary science curriculum are: *Diversity, Interactions, Systems, Cycles, Energy,* which appear to be guided by key inquiry questions, such as "what makes a cycle?". Content appears to be broken further into what is taught in the lower block (grades 3-4) and upper block of primary school (grades 5-6). For instance, students may learn about cycles in plants and animals (life cycles) in the lower block, and then cover cycles in plants and animals (reproduction) in the upper block (Tan et al., 2016, p. 160), illustrating the spiral nature of the curriculum. The thematic approach and the goal of achieving scientific literacy through student-led inquiry continue in grades 7-8. In secondary science, students revisit many topics, with *Diversity, Systems* and *Interactions* themes coherently developed from the primary science curriculum. Inquiry questions are integrated, for instance "how part of a system can affect the function of other parts in the same system?" (Tan et al., 2016, p. 165). *Scientific Endeavour* is integrated into lower secondary curriculum topics and includes "scientific inquiry", "science and technology in society", elements of the nature of science, and may ask questions like "why did this phenomenon happen?" (Tan et al., 2016, pp. 162-163). Primary science curriculum encourages teachers to adopt various strategies, from teacher-focused ones (e.g., demonstration) to more student-centred ones (e.g., drama, project work). Instruction follows a spiral approach, with concepts (e.g., how plants make food) revisited and increasing in complexity in later school years. Suggests that most learning objectives in the cognitive domain of the curriculum would be located on the lower levels of knowledge and cognitive processes in Bloom's (revised) taxonomy. This raises questions as to whether the Singaporean curriculum could help to develop deep, critical thinking in science. Practical work is assessed by teachers, especially in upper primary school, classrooms are well-equipped with laboratory equipment and curriculum guides for teachers. Trips are common, e.g., to the Singapore Science Centre. Most teachers train at the National Institute of Education – the only teacher training provider offering undergraduate and post-graduate programmes. Some argue that teacher training in Singapore is one of the main contributors towards students' high achievement in TIMSS, possibly because there is an "emphasis .. on pragmatic and instructional issues…. less on

	the analysis of theoretical constructs and more on the application of concepts and practices" (Wong et al., 1998, as cited in Lee, 2018, p. 191). Singaporean teachers have many opportunities to participate in professional development (PD) training, with the proportion of teachers participating in PD activities, education conferences and teacher networking events exceeding the 2013 OECD norms. Teachers are entitled up to 100 hours of paid PD leave. However, many primary science teachers do not have a science background and often struggle with the content. To support primary teachers, the MoE is employing more subject specialists to teach science. Various higher degrees are available for teachers, including Master's, PhD programs and the Enhancement Professional Development Continuum Model (2012), which offers funding from the MoE for graduate teachers to undertake 2–4-year Master degrees.
Tonga et al (2019)	All teachers are required to have at least a bachelor's degree to become a teacher.

Appendix D

Summary of literature around science education and curriculum in Japan (presented in ascending order)

Research	Detail
Kumano (2009)	Some citizens argue that the accelerated developments in science and technology are contributing to major problems in the Japanese society, e.g., being overwhelmed with too much information in a short space of time. The changes in the environment produced by modern human activity and the developments in science and technology need an attitudinal change from teachers and students, with many teachers believing that students are becoming too interested in an easy life.
Lau (2014)	Their study using data from the 2006 PISA assessment suggests that Japanese students valued science learning less than other East Asian nations, were more extrinsically motivated in their science learning, but low self-concept was common to all East Asian nations. With regards to science-related pedagogy (application of concepts, student-teacher interactions, hands-on-activities and investigations), Japan's teaching was more traditional than the OECD average, and "more traditional than the Chinese communities – less application focused, least interactive, and few hands on and investigative activities" (p. 9). However, there was a negative association between hands on activity and performance, as well as attitudes. Investigation was also negatively correlated with enjoyment of science learning. Considering that investigation and hands on activity are usually considered important in science learning, the findings of this study are puzzling as to the negative relationships with performance and attitudes. Furthermore, interactions in classrooms also showed negative correlations with performance, with Japan having the least interactive lessons and the largest negative associations with performance, again, posing questions about why interaction, which is seen as a valuable pedagogy, would be negatively related to learning. The 2006 PISA data suggested that about 12.2% of Japanese students had 4 or more hours of science lesson each week (compared to 32.7% OECD average), 3.4% of students had 2-4 hours of out-of-school science lessons a week (compared to 8.2% OECD average), and 5.4% had 2-4 hours of self-study/homework each week (compared to 18.6% OECD average).
Lau & Lam (2017)	In Japan most schools tend to focus on 'collections of problems designed to prepare students for university entrance' and 'one-way flow of information' (Morimoto, 2015, as cited in Lau & Lam, 2017, p. 2144). However, Japan and China were found to be below the OECD average for enquiry-based instruction. In Japan, 14% of students reported that teachers did not explain scientific ideas in class, over 50% said that whole-class discussion never happens, 17% reported that they were not allowed to explain their ideas in class and about 40% said they never did any experiments. *Interactive application* saw the least score gains in Japan and Singapore.
Isozaki (2018)	A bachelor's degree is the basic qualification required to teach from kindergarten to upper secondary school (grades 10-12) in Japan. Graduates from normal schools can only become elementary school teachers, whilst graduates from universities, colleges and higher normal schools can teach

	in secondary schools. The model of education for teachers who graduated from normal and higher normal schools has been said to focus more on professional studies but criticised as not focusing on deep content and subject matter knowledge, whilst the model for graduating from universities has been said to be based on academism and criticised for not focusing on pedagogical knowledge and teaching competencies gained through professional studies. Since the 1980s, teacher education has been continuously reformed, with elementary school teachers training to teach all subjects whilst secondary school teachers studying to teach science only. Lower and upper secondary trainee science teachers must take the following subjects to gain subject and content knowledge: physics, chemistry, biology, and Earth sciences. All of these subjects include lectures, practical work and ICT component and are intended for certificates sought by secondary school science teachers. Japanese teachers are expected to develop their practical competencies in teaching gradually, thus current pre-service teacher education has focused more on practical competencies based on professional studies and less on research theories that support science teaching and learning (e.g., content/subject matter knowledge and principles of science teaching). Type A teacher training universities (focused on professionalism) have professional schools for post-graduate programs in teacher education. Their curricular focus is on professional studies and practical application rather than theory. The Ministry of Education has also introduced a system, which expects every teacher to renew their teaching certificate after a decade by taking courses at type A, type B (academic) institutions or boards of education. However, “there is no professional standard for the teaching profession, except the curriculum framework” (the minimum number of credits of teaching subject specialties and professional studies for a teaching certificate and the minimum requirement of professional studies since 1998 – see p. 7), which is unlike other jurisdictions . TALIS results (OECD, 2014) have indicated that Japanese teachers participate in continuing professional development more than the average.
Nakamichi & Katayama (2018)	Presents the Course of Study (CS) of Biology in Japan and refers to the CS that were announced in 2008-09 and enforced in 2011-2012/13, rather than the reforms announced 2017-18 due to take place in 2020-2021/22. The 2008-09 revision deleted *Comprehensive Science A/B* and added four 2-credit basic subjects (*Basic Physics (P), Chemistry (C), Biology (B) and Earth Sciences (E)).* Students study at least three 2-credit subjects (*P/C/B/E)* or two 2-credit subjects including *Science and Our Daily Life*. It is suspected that most students will select the first one, as the content of *Science and Our Daily Life* are not considered to be included in examinations needed for university entry. Advanced science subjects are for those who are interested in specific fields of science and carry 4 credits. *Basic Biology* (Biology for all) includes the following three units: *Organisms and Genes*, *Maintenance of internal environment (homeostasis)*; *Biodiversity and ecosystems* and appears to have more content than the previous 1999 CS (see Table 4, p. 10). The topic of evolution is explored in more detail in the 2009 CS. In addition to completing each unit, students must carry out inquiry activities on topics related to the contents of units.

	Advanced Biology (Biology for interested students) has five units: *Biotic phenomena and substances; Reproduction and development; Responses to the environment; Ecosystems and environment* and *Evolution and phylogeny.* This subject aims its contents to "correspond to rapid progress in life science research in recent years", that "unity and diversity are continually emphasised" and that "various fields from the micro level to the macro level are covered" (pp. 10-12). Challenges to enforcing the biology curriculum in lower and upper secondary schools exist. For instance, teachers are expected to move away from a teacher-centred, traditional teaching to more student-centred teaching, which includes activities. This has been criticised by some as too time-consuming and difficult if teachers do not have experience in student-centred approaches. At upper secondary school, teachers may choose to deliver content in a traditional way to pass on all information needed for university entrance examinations. Changes in the content, especially in Advanced Biology, may pose difficulties for teachers who may have trained a long time ago and may not possess up-to-date knowledge of modern biology and experiments. Questions around school equipment and budget to accommodate carrying out modern experiments also exist. Suggests some possible ways of engaging in the active learning promoted by the new CS, such as: changing pre- and in-service teacher training for student-centred and active, promoting ICT use, reforming university entrance examinations and working environment for teachers as well as modernising science equipment.
Tonga et al (2019)	In Japan (as well as China and Estonia), teacher candidates must complete two assessments: a university entrance exam and a practice exam (Mete, 2013 as cited in Tonga et al., 2019).

Appendix E

Summary of literature around science education and curriculum in Estonia (presented in ascending order)

Research	Detail
Henno & Reiska (2013)	The 2006 PISA measures included questions on self-efficacy and self-concept in science, as well as interest in science. Estonian schools are divided into Estonian language instruction (ESTLI) and Russian language instruction (RUSLI) schools. Statistical differences in science performance have been found between students in the two school types, with students in ESTLI achieving higher scores in science element of the PISA assessment. This study found that socio-economic background played a greater role for students from ESTLI schools and explained less of the variance in the science performance of students in RUSLI schools. Although PISA studies have shown a link between disadvantaged background and poorer performance, this study showed that the Estonian education system is not segregating. Socio-economic status did not play an important role in explaining the differences in science performance between the different language instruction schools in Estonia. In Russian language instruction schools, where students' average performance was significantly higher than expected, students tended to report being more informed about science careers, teachers focusing on application and hands-on activities as well as having a higher future-oriented science motivation. Contrastingly, students in ESTLI schools who performed highly agreed less that they were prepared for science-related careers, that they took part in investigation, had lower instrumental motivation and general interest in learning science. Thus, although ESTLI schools students tended to perform better in science than the RUSLI students, the RUSLI students reported higher levels of motivation to learn science, information about science careers and student-oriented classroom practices. The authors suggested that RUSLI schools tend to have more "fact-based teaching and weaker development of students' meta-cognitive skills", therefore ESTLI schools may be better at preparing their students with the tools needed to succeed in PISA.
Lau & Lam (2017)	With regards to science performance, Estonia performed better in *evaluate and design scientific enquiry* (ED) compared to Asian counterparts. With regards to instructional practices, whole class discussion was common to the regions investigated in this study. The Western regions (including Estonia) tended to allow students to express their ideas in class. In Estonia, teachers tended to explain the relevance of science to daily lives more than teachers in the other jurisdictions. Adaptive instruction, teacher-directed instruction and interactive application were positively correlated with performance in all regions, but investigation and perceived feedback saw a negative association. The relationship between student scores and teacher-directed instruction was small for Estonian students.
Tonga et al (2019)	In Estonia (and Singapore), all teachers are required to have at least a bachelor's degree to become a teacher. In 2006, Estonia's education reform saw universities providing two levels: a three-year bachelor's degree and a two-year Master's degree. Primary and secondary school teachers must be qualified at Master's level. A commonality to all pre-service teacher training programmes in these high performing jurisdictions (including Estonia) is that in addition to pedagogical and content knowledge,

	pre-service teachers are taught skills for inquiry, methodology, communication, ICT studies and foreign languages. All new teachers must attend 160 hours of in-service education every five years. In service teacher training is an important part of professional development (PD) for teachers and PD is seen as continuous from pre-service education, first year of teaching and then continued PD throughout the teaching career.
Tire (2021)	Suggests that Estonians are quite self-critical by nature, which may be one of the reasons for their "driving force for improvement" (p. 118). Mentions the common belief that "all children should be education, regardless of their social standing" (Ruus, 2002, as cited in Tire, 2021, p. 102). Due to language similarities and exchange systems with Finnish universities, Estonia's education system (curricula, teaching materials and practices) has been influenced by Finland. Estonia's curriculum was introduced in schools in 1989 – two years before the jurisdiction's complete independence from the Soviet rule. The national curriculum is updated approximately every ten years and includes the learning outcomes that students should "master" at difference stages of education. There is a gap in performance between students in Estonian and in Russian schools, possibly as Russian schools focus more on basic skills and knowledge rather than application and PISA assesses the application of knowledge in other situations. Suggestions have been made about integrating the two language education systems into one to improve societal integration. Estonian teachers are highly experienced, and tend to follow more traditional, well-established teaching practices. Teachers assess students' progress frequently, but students do not tend to evaluate their own progress as much. The national curriculum lists the compulsory subjects and the number of lessons for each subject. The new curriculum was "outcome-oriented" (described the knowledge, skills, attitudes and values all together as competencies), expected of students to master. The 2011 curriculum update saw more attention placed on the development of subject strand competencies, general competencies and cross-curriculum competences that teachers should deliver in lessons. The education system was updated in 2014 as it adopted the *Lifelong Learning Strategy 2020* (MoRE, 2014), which set out the following five priority areas for development: *focus on students-centred learning* (away from the traditional teacher-focused, as well as towards more child-centred formative assessment); *competent and motivated teachers and school leadership; concordance of lifelong learning opportunities with the labour market needs*; *digital focus* (including the development of innovative digital assessment tools and more teacher training in the use of technology); and *equal opportunities and increased participation in lifelong learning.* The curriculum aims to develop a broad view in students, and many schools include subjects such as coding and robotics, as well as cooking and woodwork classes, which see mixed ability groups of boys and girls working and problem-solving together.
Eurydice (n.d.)	Teachers may choose the methods they use to achieve learning objectives and to develop competencies. Schools can choose learning materials such as textbooks, exercise books, workbooks and other aids, and throughout basic school, learning materials are free for all students. In general, homework is not usually assigned in grade 1 or for the day after a holiday or the first day of an academic quarter.
Kori (2022)	The MoER supports science-based policy making and thus develops annual plans for research projects, analyses, researches and evaluates the science education situation in

	Estonia. Grants are provided to contribute to the internalisation of research and support the next generation of researchers (Estonian Research Council, n.d., as cited in Kori, 2022). The education system is based on the Lifelong Learning Strategy 2020, which begins with general education that is underpinned by a common curriculum. The MoER selects experts (researchers, practitioners) to develop curricula and looks to other nations to support their curriculum development, e.g., Finland. In addition to the science subjects taught, many topics are also taught across the curriculum, such as environment and sustainable development, information environment, technology and innovation and values and morals. Science curriculum in basic and upper-secondary-schools emphasises the use of technology and inquiry-based learning- a student-centered, active learning approach focused on critical thinking, questioning and problem-solving (Savery, 2015, as cited in Kori, 2022), and encourages students to follow methods like those used by scientists. Science teachers use various digital resources to teach science. Certain portals of digital resources are freely accessible to teachers, and teachers can use materials designed by other teachers that are linked to the national curriculum. Teachers and students can also access digital textbooks and workbooks. Science teachers tend to train at two main universities in Estonia and are required to hold a Master's degree to teach. Various science exhibitions and events are available at higher education institutions, e.g., the Energy Discovery Centre, and schools can sign up to programs and workshops run by universities and other organisations. Schools use more emerging technologies in science teaching, such as computers, laptops, tablets, robotics tools, sensor-based technologies, video equipment as in very few cases even drones, augmented reality (AR), virtual reality and artificial intelligence tools. Some researchers (e.g., Pedaste et al., 2020) suggest that AR technologies can support cognitive, motivational and emotional learning goals in inquiry-based learning. The future of Estonian science education appears to be moving towards integrating science-related subjects (e.g., conducting a project requiring knowledge of biology, physics and geography), integrating science with technology, engineering and mathematics and even integrating arts with science, technology, engineering and mathematics. This integration could help in the development of general competencies. In the future, science education may guide students in becoming active citizens who use scientific thinking in everyday lives, thus students may be asked to carry out more citizen enquiry projects.