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Connecting IB to the NGSS

The Dual Implementation of International Baccalaureate and the Next Generation Science Standards: Challenges and Opportunities

NEXT GENERATION SCIENCE STANDARDS

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Objective

The objective of this relationship study report is to highlight the opportunities and the challenges associated with implementing the Next Generation Science Standards (NGSS) in the International Baccalaureate (IB) programmes in IB World Schools (a process to be referred to as “the dual implementation” in this report).

Although the goals of the IB programmes and the NGSS are complementary, the NGSS have set new priorities for science education in IB World Schools in the United States that are affected by the dual implementation. Educators in these schools are being called upon to ensure that their students are prepared to demonstrate proficiency in the NGSS performance indicators, while achieving the goals of the IB.

This document, produced through collaboration between the IB, Achieve and several K–12 classroom educators in IB World Schools, seeks to help teachers and administrators to:

- determine ways (both broad and specific) in which the NGSS and IB programmes can interact successfully by identifying related features between the two
- identify potential pathways to support the successful interaction between the IB and NGSS throughout K–12
- evaluate opportunities to add depth and rigour to science teaching in classrooms and identify possible gaps or shortcomings that pose considerable challenges during dual implementation
- provide evidence-based information to support classroom teachers and administrators in their decision-making process in curriculum planning as well as teaching and learning.

It is important to note that both the IB and NGSS place value on the professional judgment and expertise of teachers. This implementation will be successful and enriching because of the potential of each school, working within the perspective of the state in which it operates.

The report highlights the similarities between the value systems of the IB and NGSS through some sample one-to-one mappings. The purpose of doing so is to suggest some effective pathways for engaging in the dual implementation. Providing further one-to-one mappings of the components of the IB and the NGSS should be approached with caution, ensuring that this does not result in disempowering teachers who can be creative in exploring the numerous pathways for bringing about the dual implementation effectively. It is not possible to enjoy, experience, and reap the true benefits of “three-dimensional learning” (NRC, 2012) through a one-dimensional “one-size-fits-all” approach.

It is also pertinent to note that the IB operates in a wider international context, having to meet the needs of multiple national systems. It needs to be recognized therefore that building a relationship study report between the IB and the NGSS cannot be through a comparative analysis as the end goals of the IB and the NGSS are different as are the products themselves.

Target audience: The target audience for this report is IB teachers in all IB programmes (Primary Years Programme (PYP), Middle Years Programme (MYP) and Diploma Programme (DP)), who are responsible for the implementation of the NGSS. Implementing the NGSS with intellectual rigour and consistency within the IB calls for a “systems thinking” (Fullan, 2005) approach to curriculum design principles, classroom practices and assessment through the effective integration of science, technology, mathematics, English language arts and the social sciences. For this reason, the target audience for this report is not only science teachers.

Road map

The report begins by introducing readers to some of the congruities between the philosophies and practices of the IB and the NGSS. An in-depth exploration of each of the IB programmes within the context of the NGSS is then conducted. Focusing on the Scientific and Engineering Practices (SEP) of the NGSS and the Engineering, Design and Technology component of the NGSS, the report highlights the challenges IB World Schools encounter when engaging in the dual implementation, particularly how this component of the NGSS impacts each of the IB programmes. As the NGSS are student performance expectations, the report analyses the implications of assessment within each of the IB programmes when implementing the NGSS. The need for teacher professional development is then highlighted. Useful resources such as unit planning tools that support teachers in both the planned and the taught curriculum are identified at the end of the report.

A quick note on the structure of the report: The structure for this report required considerable thought, particularly in terms of how best to help teachers using this report through the IB continuum, that is, the progression from PYP to MYP to DP. Initially, the plan was to structure it sequentially through the IB programmes. However, upon deeper consideration (and many drafts that attempted to incorporate this structure), it became evident that such an approach would not be ideal for two reasons. First, as we know, NGSS are arranged in grade bands (K–2; grades 3–5 (PYP); 6–8 (MYP) and 9–12 (DP)). This would mean that a particular scientific concept taught in grade 4 or 5 (PYP), for instance, would need to be revisited and built upon in grades 6–8 (MYP) and again with growing complexity in the DP. The notion of the "spiral" in the curriculum, "a curriculum as it develops should revisit this basic idea repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them" (Bruner, 1960, p 13), requires teachers engaged in the dual implementation to have a holistic understanding and a bird's eye view to develop the three-dimensional breadth and rigour required by the NGSS. The current practice of teachers working in isolation within their particular IB programmes will no longer serve this purpose.

To a large extent, curriculum design principles of "backwards by design" (Wiggins and McTighe, 2004) and a "systems thinking approach" (Fullan, 2005) become the quintessential requirements of curriculum planning in schools engaged in the dual implementation. Hence, even though a particular section of the report may be of more relevance and significance to teachers in the DP, the essence of the relationship (between the IB and the NGSS) and how this affects the PYP and the MYP will not only be valuable for teachers across the continuum, but also for them to derive a holistic understanding and approach to curriculum and instruction.

Limitations: As the report focuses particularly on the dual implementation within the IB programmes, it draws extensively on IB documents and programme-specific publications throughout. It is highly recommended that this report be used in conjunction with these IB documents for precision and clarity in interpretation.

The "Assessment" section of this report draws much of its information from the publication *Developing Assessments for the Next Generation Science Standards* (NRC, 2014) published by the National Academies Press. Some of the recommendations and conclusions from this book have been highlighted in the report to provide connections and identify challenges when incorporating the NGSS within the IB. This does not indicate that some recommendations and conclusions of the study are more important than others. For this reason, it is highly recommended that this report be used in conjunction with the other publications and resources that have been identified in the references and resources sections at the end of this report. It is also important for IB educators engaging in the dual implementation to read this report with the key philosophies of the IB in mind: the IB learner profile and approaches to learning and teaching.

Introduction—NGSS overview

Implementing the NGSS framework demands a pragmatic reconsideration of science education, an approach that aims to make science education closely resemble the way scientists actually work and think (NRC, 2012). Keeping in mind that the IB is a curricular framework and the NGSS provide performance expectations, teachers engaged in the dual implementation will benefit from seeing the NGSS as bringing them one step closer (a much-needed step) towards realizing the IB's vision through measurable student outcomes. At the onset of this relationship study report, it is pertinent to mention that facilitating deep conceptual engagement through an inquiry-based approach to scientific investigation is the key connection between the IB philosophy and the NGSS performance indicators. This is brought about by the way that the NGSS structure science learning around three dimensions:

- Dimension 1—scientific and engineering practices
- Dimension 2—crosscutting concepts, that is, those applicable across science disciplines
- Dimension 3—core ideas in the science disciplines and between science, engineering and technology

In contrast to traditional science standards that posit factual knowledge as the end goal of science education, the NGSS refocuses the goals of science education on student engagement with scientific phenomena through the active development of the knowledge and skills necessary to apply their understanding to what they experience in the real world.

The NRC framework defines these goals.

Science and engineering practices (SEPs) are:

a) the major practices that scientists employ as they investigate and build models and theories about the world

b) a key set of engineering practices that engineers use as they design and build systems.

Crosscutting concepts (CCCs) have application across all domains of science. As such, they provide one way of linking across the domains in dimension 3.

Disciplinary core ideas (DCIs) build coherently across multiple years.

The NRC further highlights that each of these dimensions needs to be interwoven in every aspect of science education: curriculum, instruction and assessment. Performance expectations mapped out with their respective crosscutting concepts are available in Appendix G of the NGSS.

"The framework emphasizes that science and engineering education should support the integration of disciplinary core ideas and crosscutting concepts with the practices needed to engage in scientific inquiry and engineering design. In this report, we refer to this integration of content knowledge, crosscutting concepts, and practices as "three-dimensional science learning", or more simply "three-dimensional learning". That is, during instruction, students' engagement in the practices should always occur in the context of a core idea and, when possible, should also connect to crosscutting concepts." (NRC, 2014, p 31)

However, meeting the framework's vision for K–12 science education, demands significant change in most science classrooms as identified in Figure 1.

THE FRAMEWORK'S VISION FOR K–12 SCIENCE EDUCATION

There are four key elements of the framework's vision for science education that will likely require significant change in most science classrooms:

- a focus on developing students' understanding of a limited set of core ideas in the disciplines and a set of crosscutting concepts that connect them;
- an emphasis on how these core ideas develop over time as students' progress through the K–12 system and how students make connections among ideas from different disciplines;
- a definition of learning as engagement in the science and engineering practices to develop, investigate, and use scientific knowledge; and
- an assertion that science and engineering learning for all students will entail providing the requisite resources and more inclusive and motivating approaches to instruction and assessment, with specific attention to the needs of disadvantaged students.

Figure 1: The NRC framework's vision for K–12 science education—National Academies Press (2014, Pp 25–26)

It is pertinent to note that each performance expectation (PE) in the NGSS represents an integrated, three-dimensional student performance that is to be applied in authentic learning contexts. Since the NGSS describe science standards as student performance expectations, it is expected that classroom learning experiences will also reflect a three-dimensional approach to learning and assessment. In other words, students should learn by actively engaging in all three dimensions, to explain scientific phenomena and design solutions to problems so that their learning experiences provide them with the necessary opportunity to demonstrate proficiency of the performance expectations.

The National Research Council (NRC) articulates six goals that students should be able to achieve by grade 12 (Appendix F of the NGSS).

By grade 12, students should be able to:

- Ask questions about the natural and human-built worlds—for example: Why are there seasons? What do bees do? Why did that structure collapse? How is electric power generated?
- Distinguish a scientific question (e.g. Why do helium balloons rise?) from a nonscientific question (Which of these colored balloons is the prettiest?)
- Formulate and refine questions that can be answered empirically in a science classroom and use them to design an inquiry or construct a pragmatic solution.
- Ask probing questions that seek to identify the premises of an argument, request further elaboration, refine a research question or engineering problem, or challenge the interpretation of a data set—for example: How do you know? What evidence supports that argument?
- Note features, patterns, or contradictions in observations and ask questions about them.
- For engineering, ask questions about the need or desire to be met in order to define constraints and specifications for a solution.

Figure 2: Six goals (National Academies Press 2012). A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas, p 55)

Also Available at: https://ngss.sdcoe.net/Scientific-and-Engineering-Practices/SEP1-Asking-Questions-and-Defining-Problems

In order to realize these six goals, the NRC considers the following eight practices to be essential elements of the K–12 science and engineering curriculum.

1. Asking questions (for science) and defining problems (for engineering).

2. Developing and using models.

3. Planning and carrying out investigations.

4. Analyzing and interpreting data.

5. Using mathematics and computational thinking.

6. Constructing explanations (for science) and designing solutions (for engineering).

7. Engaging in argument from evidence.

8. Obtaining, evaluating, and communicating

Figure 3: Eight practices (National Academies Press, 2012, p 42) (NGSS Appendix F, p 1)

As pointed out by the NRC:

"The framework and subsequent standards will not lead to improvements in K–12 science education unless the other components of the system—curriculum, instruction, professional development, and assessment—change so that they are aligned with the framework's vision." (NRC, 2012, p 17)

The performance expectations of the NGSS focus on **understanding and application** as opposed to **memorization of facts devoid of context**, which is also emphasized in the IB (Peterson, 1972). The NGSS framework goes on to emphasize that:

"... learning about science and engineering involves integration of the knowledge of scientific explanations (i.e. content knowledge) and the practices needed to engage in scientific inquiry and engineering design. Thus the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K–12 science education". (Appendix A of the NGSS, p 15)

Thinking through the three-dimensional learning in the NGSS

The most fundamental shift from traditional science education to the NGSS is a shift in the goals of science education: from content knowledge (facts) alone to the application of knowledge and skills to explain phenomena in the world, and designing solutions to real-world problems. Thus, the NGSS set forth goals for deep understanding and application of science by explicitly asking students to use three different but equally important dimensions to explain phenomena or design solutions in every performance expectation:

- disciplinary core ideas
- science and engineering practices
- crosscutting concepts.

Take photosynthesis as an example. A student would likely be successful in a traditional science classroom if they could:

a) define photosynthesis

b) list the necessary steps, including products and reactants.

In an NGSS-aligned classroom, knowing these facts is only part of what students need to be able to demonstrate. In order to demonstrate proficiency in a performance indicator students will need to be able to apply this information in context, for example, for a specific phenomenon involving photosynthesis:

- How does energy flow through the system, and how does the transformation of energy from one form to another occur?
- How does the interdependence of the relevant parts of the plant (as a system) support the process?
- What would happen to the stored chemical energy if certain factors in the environment were altered?

- What are the relationships between stored chemical energy in molecules within cells and the energy plants and animals need on a macroscopic scale for growth, repair and behaviour?
- How is this relevant to real-world phenomena, like agriculture or ecosystem health?

Such an approach is in stark contrast to traditional science instruction, which often includes decontextualized and unauthentic mimicry of "real science" (for example, memorization of the linear scientific method and "doing science" as opposed to viewing science learning as an exploratory process of trial and error). Implicit connections within and across science disciplines that were never made explicit to students (therefore assuming that all students could actually apply those connections) are now being explicitly addressed within each of the dimensions. (For example, using an understanding of energy flows through physical science systems to inform energy flows in life science systems; observing differences in patterns at different scales, and using this to think through how phenomena at one scale may impact phenomena at other scales within a system).

To think through what three-dimensional learning looks like, and to facilitate strategies for incorporating it into classroom learning experiences, consider what students' learning would miss out on if any one of the three dimensions were left out.

Without the science and engineering practices what might it look like?

This performance indicator would ask students to "describe the function of a cell as a whole and ways parts of cells contribute to the function". What would this look like? It is likely that without modelling, it may manifest as a list or a picture detailing the parts of a cell and what they do, whereas modelling would help students to:

- identify the relevant elements or components of the system, making sense of the specific phenomenon they are dealing with
- explicitly organize the relevant evidence, including scientific information, that connects those components to the phenomenon
- explicitly organize scientific reasoning (both logic as well as the application of scientific theories and laws) that connects the evidence, and allows mechanisms to be described and predictions to be made.

In this example, if the practice (including both the knowledge and skill associated with it) were not being used in conjunction with the other dimensions students would not have access to a model that enables them to make connections between evidence, reasoning and the phenomenon at hand. It would also be difficult to think through these scientific ideas holistically instead of as discrete facts to remember.

MS-LS1-2 Develop and use a model to describe the function of a cell as a whole and ways parts of cells contrubute to the function. [Clarification Statement: Emphasis is on the cell functioning as a whole system and the prinmary role of identified parts of the cell, specifically the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.] *[Assessment Boundary: Assessment of organelle structure/function relationships is limited to the cell wall and cell membrane. Assessment of the function of the other organelles is limited ot their relationship to the whole cell. Assessment does not include the biochemical function of cells or cell parts.]*		
Modeling in 6-8 builds on K-5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop and use a model to describe phenomena	**LS1.A: Structure and Function** • Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.	**Structure and Function** • Comples and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function

Figure 4: Developing a model. Available at http://www.nextgenscience.org

Without the crosscutting concepts what might this example look like?

Without explicit reference to the crosscutting concepts, the performance expectations would no longer require students to analyse parts of a system (here the functions of structures that make up a cell) to describe the overall function of the cell as a part of a bigger system. Without using the understanding that systems are made up of parts whose functions independently and together give rise to the function of the system as a whole; this performance expectation would likely manifest as a physical representation or drawing of different structures within a cell, with descriptions of their individual functions, perhaps in the context of the cell (for example, mitochondria generate the energy for the cell; the cell membrane controls what enters and leaves the cell). This particular element of the crosscutting concept may help students to:

- recognize that systems can be broken down and visualized in smaller pieces
- recognize that the functions of those small pieces, individually and collectively, contribute to the overall function of the system
- make observations about what evidence of cell death is present, think about how different structures of the cell may be contributing, consider what we might expect to see if one structure was contributing primarily, how those internal structures depend on one another to be fully functional, and therefore how the parts of the cell are contributing to the phenomenon. By understanding individual functions and interactions between parts of a system, the overall function can be analysed, understood, and predicted (for example, if the cell is dying).

Without the crosscutting concept, students are missing the link to the "big idea", both in terms of scientific phenomena, as well as how a cell's overall function is related to the function of the components that make up a cell, much like what you might see in ecosystems and weather systems.

Without the disciplinary core idea what might this look like?

This may be difficult to visualize given the performance expectation, but would be similar to asking students to develop a model or describe "systems" without any kind of meaningful anchoring context on which to build deep conceptual understanding, which in turn would be less useful as a tool to make sense of the world. Science learning gets reduced to rote memorization experienced in a vacuum.

Using the three equally important dimensions together leads students to emphasize evidence, reasoning and making meaningful connections between content and scientific phenomena. This allows students to develop and use meaningful, authentic and flexible science skills and knowledge to be applied across many familiar and novel situations and to more critically consume and utilize science ideas in their daily lives. Since the performance expectations demand proficiency in three-dimensional learning, instruction and daily classroom experiences must also reflect three-dimensional learning; it is unreasonable to expect that students can be taught each of the dimensions in isolation and still be able to make the connections and demonstrate understanding when assessed.

It is pertinent to note that in the classroom, many practices and crosscutting concepts may be used to help students reach deep conceptual understanding. Parts of different disciplinary core ideas may come together in lessons and units to address a specific phenomenon or problem at hand. Lessons building towards the performance expectation given as an example could include argumentation, obtaining and evaluating information, analysing data, making connections with related concepts of scale and proportion or cause and effect, observing chemical reactions and atomic rearrangement, energy flows through systems, and many other combinations of dimensions, practices and disciplinary core ideas depending on the specific approach.

Integration of science and engineering

The NGSS aim to make the connections between science and engineering explicit for students to facilitate their ability to be innovative critical thinkers when defining problems and when having to design solutions to problems, while still expecting them to demonstrate some key competencies specific to engineering (for example, iteration to optimize a design). Engaging in the engineering process gives students experience of defining problems, as well as of defining, testing, revising, and optimizing solutions.

The NGSS intend for engineering to be experienced in the context of science, with science informing the definition of problems and the design of solutions, and the design process helping to deepen students' understanding of science. Moreover, explicitly integrating engineering into science may provide additional access points for students. For example, some students may engage more in problem-solving (engineering) scenarios than in those that seek to explain phenomena in the natural world. By providing opportunities for both types of experiences, students gain important critical thinking and problem-solving skills in the context of their science education, as well as exposure to rich engineering experiences. The emphasis of learning and teaching in the IB (and its assessments) on authentic, real-world tasks brought about through interdisciplinary study with product and digital design is closely aligned to the NGSS goals, which is further substantiated through the IB's emphasis on developing critical thinking and problem-solving capabilities among students through a scientific world view.

The vision of the NRC framework of actively engaging students in science and engineering practices through the application of crosscutting concepts to deepen understanding in each of the field's disciplinary core ideas very clearly and deeply resonates with the philosophy of the IB. Working on the principle of backwards by design (Wiggins and McTighe, 2004), IB World Schools that are in the process of integrating the NGSS can quickly see the overarching synergy between the philosophies and practices of the IB and the NGSS.

Overview—IB

Alec Peterson (the first Director General of the IB appointed in 1987) envisioned a curriculum that moved learning beyond "watertight compartments", a curriculum that arose from a desire for "teaching of minds well informed rather than minds well stuffed" (Peterson, 1987, pp 47–48). According to Peterson (1987, p 47), "what matters is not the regurgitated interpretations of facts but the development of powers of the mind or ways of thinking that can be applied to new situations". Peterson (1987, p 48) draws on Bruner (1960) in clarifying that:

"Teaching specific subjects without making clear their context in the broad fundamental structure of a field of knowledge is uneconomical in several deep senses ... the knowledge one has acquired without sufficient understanding to tie it together is likely to be forgotten".

In this sense, teaching and learning in the IB celebrates the many ways people work together to construct meaning and make sense of the world. Through the interplay of asking, doing and thinking, this constructivist approach leads towards collaborative classrooms. An IB education empowers young people for a lifetime of learning: independently and in collaboration with others. It prepares a community of learners to engage with global challenges through inquiry, action and reflection (IBO, 2013, p 4).

All IB programmes share common beliefs and values about teaching and learning science (IBO, 2014b).

- **International dimension:** Students develop an appreciation that science requires open-mindedness and freedom of thought transcending gender, political, cultural, linguistic, national and religious boundaries.
- **Aesthetic dimension:** Students engage with the complexities, intricacies and beauty of science, which arouses their curiosity and heightens their learning.
- **Ethical dimension:** Students reflect on the ethical, social, economic, political, cultural and environmental implications of using science to solve specific problems. Students develop a personal, ethical stance on science-related issues.
- **Learning through investigation:** Students construct meaning by designing, conducting and reflecting on scientific investigations. The scientific process, which encourages hands-on experience, inquiry, and critical thinking, enables students to make informed and responsible decisions, not only in science but also in other areas of life.
- **Collaboration:** Students are provided opportunities to work individually and with their peers to learn about science within and beyond the classroom. They develop safe and responsible working habits in practical science.

In terms of curriculum and instruction, moving beyond the regurgitation of content knowledge to facilitate deep conceptual learning fostered through inquiry-based methodologies is the underpinning philosophy of both the IB and the NGSS. A quick look at the essential components of the IB programmes, the components that make it a student-centred, conceptually engaging framework implemented through meaningful and sustained inquiry, is critical for understanding how the above philosophy will translate into classroom practice in the particular context of understanding the congruence of the IB science courses and the NGSS. In order to understand the areas of convergence of the IB science courses with the NGSS and to deconstruct some of the challenges, the following section briefly highlights the critical components of the IB programmes across the continuum.

Sustained inquiry

"The scientific mind does not so much provide the right answers as asks the right questions." (Claude Lévi-Strauss)

Inquiry, in the broadest sense, is the process that is used to move towards deeper levels of understanding. Inquiry involves speculating, exploring, questioning and connecting. In all IB programmes, inquiry develops curiosity and promotes critical and creative thinking (IBO, 2014b, p 29).

Science within the IB programmes encourages inquiry, curiosity and ingenuity. Learners should develop an understanding of the resources of a rapidly changing scientific and technological society and how to use those resources wisely (IBO, 2014b, p 15). Sustained inquiry forms the centrepiece of the written, taught and assessed curriculum in IB programmes. IB programmes feature structured inquiry into established bodies of knowledge as well as into complex problems. In this approach, prior knowledge and experience establish the basis for new learning, and students' own curiosity provides the most effective provocation for learning that is engaging, relevant, challenging and significant (IBO, 2013, p 4).

Committed to inquiry since its inception, the PYP highlights the notion that spontaneous, student-initiated science inquiries will occur that are not directly related to any planned units of inquiry. These are valuable teaching and learning experiences in themselves and they provide teachers and students with the opportunity to apply the pedagogy of the PYP to authentic, of-the-moment situations (IBO, 2008a, p 1).

The inquiry-based approach is also emphasized in the MYP. With inquiry at the core, the MYP science framework encourages students to investigate issues independently and collaboratively through research, observation and experimentation (IBO, 2014b).

In terms of assessment, scientific inquiry enables students to develop a way of thinking and a set of skills and processes that they can use confidently to tackle the internal assessment component of DP biology, chemistry and physics. This is further supported by the summative examinations and the use of on-screen assessments offers a more authentic experience to assess student understanding. Moreover, the MYP sciences objectives and assessment criteria (A–D) are aligned with the DP sciences objectives and internal assessment criteria, supporting the smooth transition from the MYP to the DP (IBO, 2014b, p 15).

Concepts and conceptual understanding

Understanding that "every discipline has a conceptual structure" that comprises of topics, facts, generalizations, principles and theories (Erickson, 2010, p 2) and understanding the synergy between the factual and conceptual domains of knowledge is critical. The "structure of knowledge" as proposed by Erickson (2010, p 31) that enables transitioning from traditional "two-dimensional" teaching (focused on memorizing content) to "three-dimensional" teaching (using the factual knowledge to build deeper conceptual understandings) offers much clarity.

The following is an example of how the structure of knowledge scaffolds the topic "organisms and adaptations" in science from factual understanding to conceptual levels, thereby facilitating the transition from fact-based teaching to "idea-centred" (Erickson, 2010) teaching, that "environmental factors influence an organism's biology and behaviour pattern".

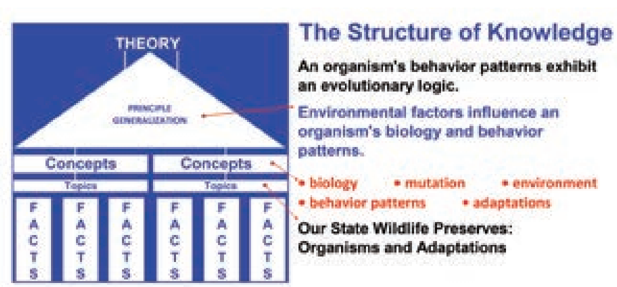

Figure 5: The structure of knowledge (Erickson, 2010)

The PYP defines "concepts" as "powerful ideas that have relevance within the subject areas but also transcend them and that students must explore and re-explore in order to develop a coherent, in-depth understanding" (IBO, 2007, p 10). A concept is thus a "big idea"—a principle or notion that is enduring, the significance of which goes beyond particular origins, subject matter, or place in time. Concepts in the structure of knowledge represent the vehicle for student inquiry into issues and ideas of personal, local and global significance, providing the means by which they can explore the essence of the sciences.

Conceptual learning focuses on broad and powerful organizing ideas that have relevance within and across subject areas. They reach beyond national and cultural boundaries. Concepts help to integrate learning, add coherence to the curriculum, deepen disciplinary understanding, build the capacity to engage with complex ideas and allow transfer of learning to new contexts. PYP and MYP students encounter defined sets of key concepts, and students in the DP and Career-related Programme (CP) further develop their conceptual understanding (IBO, 2013, p 6).

Prior to the NGSS, teachers had to work on developing generalizations that brought together factual and conceptual understanding. Creating a vertical alignment of the generalizations (K–12) was very challenging for schools, if they attempted it at all. With the NGSS, this burden has been removed from schools, as the performance expectations developed by curriculum experts already provide them with this.

Here is a typical example of how the NGSS articulate the crosscutting statement "Energy and matter" with scaffolding (K–12).

Further specific examples based on the "structure of knowledge" can be developed using the crosscutting concepts identified by the NGSS and the "key and related concepts" used by the IB. (Student prompts for articulating the understanding of crosscutting concepts is available in Appendix 4).

The IB learner profile

Unpacking and implementing the NGSS in IB World Schools needs to be done in light of the approaches to teaching and learning (ATL) and the learner profile. This, complemented by the inquiry-based, conceptually focused curriculum and instruction that permeates the IB programmes, brings about a striking alignment in the overarching philosophy and approach of the IB and the NGSS. Any review of the critical components of the IB programmes is not complete if it does not state that teaching and learning in the IB programmes must take place in the context of the IB learner profile (IBO, 2008b, p 12).

Crosscutting statements (Energy and matter)

- K–2 Objects may break into smaller pieces, be put together into larger pieces, or change shapes.
- 3–5 Energy can be transferred in various ways and between objects.
- 6–8 Energy may take different forms (e.g.: energy in fields, thermal energy, energy of motion).
- 9–12 Students understand that energy cannot be created or destroyed, only moves between one place and another place, between objects and/or fields, or between systems.

Figure 6: NGSS crosscutting statements. Available at: http://www.nextgenscience.org

Approaches to learning (ATL)

"The focus of approaches to learning in the MYP is on helping students to develop the self-knowledge and skills they need to enjoy a lifetime of learning. ATL skills empower students to succeed in meeting the challenging objectives of MYP subject groups and prepare them for further success in rigorous academic programmes like the IB Diploma Programme and the IB Career-related Certificate." (IBO 2014a: 20)

ATL has always been part of IB teaching.

"What is of paramount importance in the pre-university stage is not what is learned but learning how to learn ... What matters is not the absorption and regurgitation either of fact or pre-digested interpretations of facts, but the development of powers of the mind or ways of thinking which can be applied to new situations and new presentations of facts as they arise." (Peterson, 1972)

(Note: More details about ATL are available on the IB's online curriculum centre.)

IB World Schools engaged in the dual implementation will benefit from viewing the NGSS as the much-needed next step towards realizing the IB's vision of curriculum and instruction through measurable outcomes. Through a sustained, inquiry-based approach to curriculum and instruction, the IB philosophy calls for teaching and learning to move beyond the repetition of factual content in order to empower students to engage in critical thinking and deep conceptual understanding. Similarly, the NGSS strive to focus on a limited number of disciplinary core ideas and crosscutting concepts to enrich the application of scientific practices and the understanding of core scientific ideas, designed in a way that students continually build on and revise their knowledge and abilities over multiple years.

The overarching goal of both the IB and the NGSS in moving beyond teaching and learning of science as a body of factual information to fostering scientific inquiry (aimed at deep conceptual engagement) is an area of powerful synergy (Erickson, 2012) between the two. In fact, the NGSS only reinforce and strengthen the IB philosophy and practice of curriculum and instruction followed since its inception in 1968.

Programme-specific sections—congruence and challenges

Primary Years Programme

The Primary Years Programme (PYP) introduced in 1997 is a curriculum framework for "students aged 3 to 12 that focuses on the development of the student as an inquirer, both in the classroom and in the world outside" (IBO, 2014). The PYP is believed to have been:

"the outcome of a sustained vision of the former International Schools Curriculum Project ... to produce a common international curriculum that helps develop international-mindedness among children". (IBO, 2009a, p 1)

A "curriculum framework" can be defined as:

"a group of related subjects or themes, which fit together according to a predetermined set of criteria to appropriately cover an area of study. Each curriculum framework has the potential to provide a structure for designing subjects and a rationale and policy context for subsequent curriculum development of these subjects". (Marsh, 2006, p 19)

The PYP, committed to the inquiry-based approach to teaching and learning, articulates the relationship between the written, the taught and the learned curriculum in the form of the following open-ended questions (IBO, 2000, p 9):

- "What do we want to learn?": articulates the written curriculum and identifies what student learning should take place within a curriculum framework.

- "How best will we learn?": articulates the taught curriculum and identifies the theory and application that underpins effective classroom practice.
- "How will we know what we have learned?": articulates the learned curriculum through the theory and application of effective assessment.

The PYP curriculum framework is also broad and inclusive in that it places equal importance on all student activities, both academic and non-academic, believing that all have an impact on student learning (IBO, 2000, p 9). A balance between knowledge, understanding and skills is aimed at by placing emphasis on the five essential elements of the written curriculum (knowledge (disciplinary and transdisciplinary), key concepts, transdisciplinary skills, attitudes and action) together with the IB learner profile to ensure "a coherent learning experience for each student throughout each year or grade level, and from one year or grade level to another" (IBO, 2009a; IBO, 2010c). This enables concurrency of learning which is further supported by the requirement that "mathematics, languages of instruction, social studies and science need to be the responsibility of the classroom teacher: the teacher with whom the students spend most of their time" (IBO, 2010c).

An understanding of the PYP framework (in fact of all four IB programmes) is incomplete without mentioning the constructivist belief that has underpinned the programme since its inception in 1997. Following the lines of constructivist theory, Marshman (2010, p 8) argues that:

"cognition and learning is a psychological construct, a process that is idiosyncratic to each individual learner because of prior experience and individual propensities … and the process is only sometimes, and perhaps rarely, predictable in that learning rarely occurs in a linear way and is different for different individuals".

Marshman (2010, p 8) further draws on Gardner (1999) to discourage the notion of viewing learners as "blank slates or empty vessels" and encourages the view that learners have different propensities and learning styles and that learners are, through their learning experiences, often engaged in making cognitive connections in different ways.

Gardner (1999, p 74) also embraces the notion that "less is more", encouraging the exploration of fewer topics in greater depth rather than covering a wide range of topics with minimal exploration, through an interdisciplinary approach that initiates the idea that "literacies, skills and disciplines ought to be pursued as tools which allow one to enhance one's understanding of important questions, topics and themes". Following several years of research that analysed various national systems and curricular models in international schools, it was concluded that:

"there are clusters of important ideas which can usefully be grouped under a set of overarching concepts, each of which has major significance, regardless of time or place, within and across disciplines ... Thus a conceptual framework for the PYP curriculum, structured around a set of key concepts was designed, which serve as labels for bringing together clusters of interesting ideas". (IBO, 2000, p 13)

This aligns with Gardner's theories (1999, p 85) that seek to explore content through the "big ideas" or concepts by asserting that:

"the key step is the recognition that a concept can only be well understood and can only give rise to convincing performances of understanding if an individual is capable of representing that core in more than one way, indeed, in several ways. Moreover it is desirable if the multiple modes of representing draw on a number of symbol systems, intelligences, schemas and frames".

It is worth mentioning that this does not in any way mean disciplinary expertise is not important, but it is not "another call for projects" (Gardner, 1999, p 87). Thus, the PYP promotes the idea that teachers and students spend significant time exploring topics in greater depth and detail, through a transdisciplinary approach. Drawing on the notion supported by educationists such as Gardner (1999, p 74), the PYP approaches the task of identifying the areas of knowledge through "six transdisciplinary themes" (IBO, 2009a, p 8):

- Who we are
- Where we are in place and time
- How we express ourselves

- How the world works
- How we organize ourselves
- Sharing the planet

The six transdisciplinary themes:

"are supported by knowledge, concepts and skills from the traditional subject areas but utilize them in ways that transcend the confines of these subjects, thereby contributing to the transdisciplinary model of teaching and learning". (IBO, 2008a, p 9)

By identifying concepts that have relevance within each subject area, and across and beyond all subject areas, the PYP has defined an essential element for supporting its transdisciplinary model of teaching and learning. These concepts provide a structure for exploration of significant and authentic content. In the course of this exploration students deepen their understanding of the concepts (IBO, 2007, p 24).

PYP and the NGSS—correlation and congruence

The following table maps out the correlation between the PYP key concepts and the NGSS crosscutting concepts to bring out the synergy between the two complementary approaches towards building a sustainable approach in implementing the above in practice.

IB PYP KEY CONCEPTS	NGSS CROSSCUTTING CONCEPTS
Form	Structure and function
Function	
Causation	Cause and effect
Change	Stability and change
Connection	Interdependence of engineering and technology
Perspective	Scale, proportion and quantity

Figure 7: PYP key concepts and NGSS crosscutting concepts

As already mentioned, while the purpose here is not to engage in a "matching exercise" (such an approach will reduce the notion of "concepts" to "topics" resulting in a "tick the box" exercise), the articulation of the congruence to some extent will help teachers realize how the PYP and the NGSS complement each other in both philosophy and in action (the written and taught curriculum). In addition to the transdisciplinary themes, the knowledge component of science in the PYP is explored through four strands. The IB emphasizes that the science component of the PYP should be characterized predominantly by concepts and skills rather than by content. The knowledge component of science (science scope and sequence) in the PYP is arranged into four strands: living things, Earth and space, materials and matter, and forces and energy.

Science strands	
Living things	The study of the characteristics, systems and behaviours of humans and other animals, and of plants; the interactions and relationships between and among them, and with their environment.
Earth and space	The study of planet Earth and its position in the universe, particularly its relationship with the sun; the natural phenomena and systems that shape the planet and the distinctive features that identify it; the infinite and finite resources of the planet.
Materials and matter	The study of the properties, behaviours and uses of materials, both natural and human-made; the origins of human-made materials and how they are manipulated to suit a purpose.
Forces and energy	The study of energy, its origins, storage and transfer, and the work it can do; the study of forces; the application of scientific understanding through inventions and machines.

Figure 8: PYP science strands

These strands are similar in organizational function to the NGSS disciplines: life science, Earth and space science, physical science, engineering. When planning a unit of inquiry, PYP teachers can map content to the NGSS using the table below. Strands and disciplines are similar in that they are broad overarching categories of concepts. However, they are dissimilar in that within the NGSS, engineering is considered a discipline of science for all grades K–12.

PYP STRANDS	NGSS DISCIPLINES
Living things	Life science
Earth and space	Earth and space science
Materials and matter	Physical science
Force and energy	Physical science

Figure 9: PYP strands and NGSS disciplines

Within the NGSS, specific sub-topics for each of these categories are covered in each grade level and structured in a way that knowledge within each discipline builds logically over time, and with the other disciplines. PYP teachers can use these ideas within each grade level to structure learning experiences inside and outside the programme of inquiry.

Assessment is an important part of each of the units of inquiry. In addition to assessing student understanding it provides students with a valuable opportunity to reflect on their learning experiences which in turn offers valuable feedback to teachers to inform further planning. Through school-based ongoing authentic assessments, PYP schools seek to identify what students know, understand and (can) do at different stages in the teaching and learning process. In the PYP, learning and assessment for learning is a continuous practice, through which teachers identify student needs and use assessment data to inform planning. The NGSS, designed as performance expectations for each grade level in K–5, can be used as outcomes for units of inquiry. Since the NGSS foster a three-dimensional approach rather than assessing science content and science skills separately, assessment tasks in the PYP will need to reflect both the depth and rigour of the standards. Through the inquiry-based, student-driven, conceptually engaging approach that PYP transdisciplinary learning facilitates, this is certainly an achievable goal.

PYP and the scientific and engineering practices (SEP) of the NGSS

While going beyond the regurgitation of content knowledge to facilitate deep conceptual learning fostered through inquiry-based methodologies is the underpinning philosophy of both the IB and the NGSS, the scientific and engineering practices within the NGSS (particularly in relation to engineering design and technology) seem to pose some challenges within the IB programmes.

The essence of the NGSS goals and practices (described previously) is succinctly articulated by the IB (IBO, 2014, p 7), as it requires PYP schools to be "committed to a constructivist, inquiry-based approach to teaching and learning that promotes inquiry and the development of critical-thinking skills". Educational scholars such as Wiggins and McTighe (2004) also support this notion of fostering a lifelong passion for learning through sustained inquiry. They state that:

"Students cannot possibly learn everything of value by the time they leave school, but we can instill in them the desire to keep questioning throughout their lives." (Wiggins and McTighe, 2004)

In the PYP, science is viewed as "the exploration of the biological, chemical and physical aspects of the natural world, and the relationships between them". The PYP also highlights the notion that our understanding of science is constantly changing and evolving, and the purpose of science education is to create (within the PYP learners) "an appreciation and awareness of the world as it is viewed from a scientific perspective" (IBO, 2008a, p 1). The PYP also recognizes the importance of learning science **in context** in order to encourage and foster the learner's natural curiosity of developing an understanding of the world.

PYP SCIENCE SKILLS	NGSS SCIENCE AND ENGINEERING PRACTICES
Observe carefully in order to gather data	Planning and carrying out investigations
Use a variety of instruments and tools to measure data accurately	Planning and carrying out investigations
Use scientific vocabulary to explain their observations and experiences	Obtaining, evaluating and communicating information
Identify or generate a question or problem to be explored	Asking questions and defining problems
Plan and carry out systematic investigations, manipulating variables as necessary	Planning and carrying out investigations
Make and test predictions	Developing and using models
Interpret and evaluate data gathered in order to draw conclusions	Analysing and interpreting data, Constructing explanations and designing solutions, Engaging in arguments from evidence
Consider scientific models and applications of these models (including their limitations)	Developing and using models

Figure 10: PYP science skills and NGSS SEPs

Purzer et al (2014) point out that the NGSS recommend an integration of engineering into science through two modes:

a) as a pedagogical approach to teaching science content

b) as an important content area in and of itself.

The NGSS framework draws attention to the fact that the term "engineering" is used in a very broad sense to mean "any engagement in a systematic practice of design to achieve solutions to particular human problems". Also, the NGSS points out that the term technology should actually be used "to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices".

The previously described approach is valuable, but incorporating it into the PYP is a considerable challenge. Taking into consideration development and learning during early childhood (3–4 years), the PYP recommends that schools be flexible and sensitive to the reality that some units will need more time than others. Thus the major area of concern seems to be the extent to which the disciplinary core ideas can be explored in depth in the PYP by incorporating engineering design practices. Therefore the PYP faces some challenges and there is a danger that teachers will become "coverage-centred" if all of the disciplinary core ideas have to be explored (K–5/6th grade) through a conceptually engaging and sustained inquiry-based methodology as recommended by both the IB and the NGSS.

Another area of concern within the PYP regards a key point that the NRC makes on fostering inquiry. Due to the many ways in which the scientific community has interpreted the term "inquiry" over time, the NGSS highlights that a part of their intent in articulating the practices in dimension 1 of the NGSS was "to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires". The NRC further explains that unless students engage in scientific practices themselves, they will neither be able to appreciate scientific knowledge nor comprehend scientific practices (NRC, 2012, p 30):

"As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand".

This calls for inquiry to be facilitated through engineering design-based practices, which for some PYP teachers may involve a paradigm shift, moving from a structured inquiry method (as they are currently engaging in) to a practice-based approach to inquiry. Thus, if the engineering and design components of the NGSS are to be explored by PYP students by personally engaging in scientific inquiry in each of the DCIs, there seem to be considerable challenges in terms of time, resources and assessments that PYP schools might initially face. This is not to say that it is impossible for schools to meaningfully integrate engineering, design and technology within the PYP, but rather to acknowledge the need for focused professional development for teachers. Schools also need to set aside quality time to understand and develop a sustainable plan towards realizing the vision of the NGSS.

It is worth acknowledging that assessments in the PYP (including the culminating exhibition) do offer the scope and possibility of incorporating assessments that demand the demonstration and understanding of this synergy, though planning this will involve considerable time and resources. This has been explored in detail in the "Assessment" section of this report.

Middle Years Programme

The International Schools Association Curriculum (ISAC) initiated in the 1980s by the International Schools Association aimed to develop a curriculum that "raised international awareness in young people with emphasis on skills, attitude and knowledge to participate in an increasingly global society". This is said to be the forerunner of the MYP curriculum (Marshman, 2010, p 5). Schools adopting the MYP are required to organize learning in such a way that students will become increasingly aware of the connections between subjects, content and the real world:

"With inquiry at the core, the MYP sciences framework aims to guide students to independently and collaboratively investigate issues through research, observation and experimentation. The MYP sciences curriculum explores the connections between science and everyday life. As they investigate real examples of science applications, students discover the tensions and dependencies between science and morality, ethics, culture, economics, politics, and the environment." (IBO, 2014c)

Within the MYP framework, the NGSS disciplinary core ideas can represent content targets, so that NGSS performance expectations are reached within the constructs of the framework. In the MYP, interdisciplinary learning is the process by which students come to understand bodies of knowledge and ways of knowing from two or more disciplines or subject groups and integrate them to create new understanding.

"Students demonstrate interdisciplinary understanding when they can bring together concepts, methods, or forms of communication from two or more disciplines or established areas of expertise to explain a phenomenon, solve a problem, create a product, or raise a new question in ways that would have been unlikely through a single discipline." (Boix Mansilla, 2010)

In effective interdisciplinary learning, the integration of disciplinary perspectives or subject areas is purposeful. Integrating disciplinary perspectives is not a goal in itself but rather a means to deepen students' understanding of their world and support them in becoming more competent in the same. (IBO, 2014, Pp 3–4)

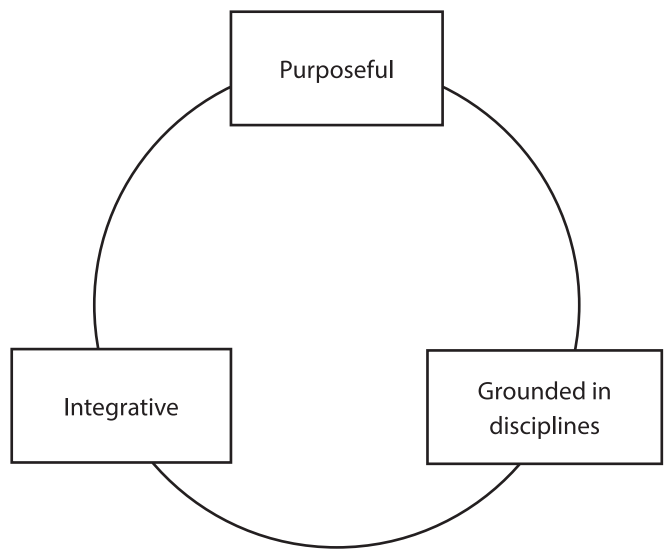

Figure 11: Key qualities of interdisciplinary learning. (IBO, 2014)

The emphasis on interdisciplinary and real-world connections as emphasized by the NGSS is brought about succinctly through the holistic aims of science learning in the MYP that encourage and enable students to:

- understand and appreciate science and its implications
- consider science as a human endeavour with benefits and limitations
- cultivate analytical, inquiring and flexible minds that pose questions, solve problems, construct explanations and judge arguments
- develop skills to design and perform investigations, evaluate evidence and reach conclusions
- build an awareness of the need to effectively collaborate and communicate
- apply language skills and knowledge in a variety of real-life contexts
- develop sensitivity towards the living and non-living environments
- reflect on learning experiences and make informed choices.

MYP and the NGSS—correlation and congruence

The MYP values the notion that learning science needs to go beyond learning technical jargon. With inquiry at the core, the MYP sciences framework aims to guide students to independently and collaboratively investigate issues through research, observation and experimentation. Scientific inquiry also fosters critical and creative thinking about research and design, as well as the identification of assumptions and alternative explanations (MYP sciences, 2014–15 p 4). It is also worth noting that in every year of MYP sciences, all students must independently complete a scientific investigation that is assessed based on inquiring and designing (criterion B) as well as on process and evaluation (criterion C).

Thus, students develop scientific knowledge (facts, ideas, concepts, processes, laws, principles, models and theories) and apply it to solve problems and express scientifically supported judgments. In order to reach the objectives of the sciences, students should be able to:

- explain scientific knowledge
- apply scientific knowledge and understanding to solve problems set in familiar and unfamiliar situations
- analyse and evaluate information to make scientifically supported judgments. (IBO, 2014b, p 9)

In the MYP, conceptual understanding is framed by prescribed key and related concepts. Teachers must use these concepts to develop the curriculum. Schools may identify and develop additional concepts to meet local circumstances and curriculum requirements. Students use conceptual understanding as they solve problems, analyse issues, and evaluate decisions that can have an impact on themselves, their communities and the wider world (IBO, 2014b, p 18).

NGSS crosscutting concepts	MYP key/related concepts
Patterns	Patterns
Cause and effect	Movement, transformation, consequence
Scale, proportion and quantity	Models
Systems and system models	Systems and models
Energy and matter	Energy
Structure and function	Form
Stability and change	Change, balance, movement

Figure 12: MYP concepts and NGSS crosscutting concepts

The MYP structures sustained inquiry in sciences by developing conceptual understanding in global contexts. Teachers and students develop a statement of inquiry and use inquiry questions to explore the subject. Through their inquiry, students develop specific interdisciplinary and disciplinary approaches to learning skills (IBO, 2014b, p 29).

The high degree of congruence between MYP assessments and the three-dimensional science learning in the NGSS is explored in depth in the "Assessment" section of this report. However, it is critical to note at this point that as in the NGSS, the MYP also highlights that the intention of science learning is not "to create a specific body of factual knowledge that must be mastered in year 5 in order to be successful in onscreen examinations". Rather, the MYP assessments are designed to go beyond gauging students' factual understanding and focus more on the deeper conceptual understanding realized through hands-on scientific and engineering practices.

Although assessment in the MYP is internal, "carried out by teachers and relies on their professional expertise in making judgments based on the prescribed IB MYP assessment criteria defined in the subject guides" (IBO, 2014), schools also have an option to have a sample of the assessments of students in the last year of the MYP moderated externally. MYP on-screen examinations (eAssessments) are formal external examinations, and are available in biology, chemistry, physics and integrated sciences. Within this, the MYP offers immense possibilities to assess three-dimensional science learning objectives as articulated by the NGSS. The MYP on-screen assessment blueprints document the close connection of large-scale assessment with subject-group objectives, classroom learning engagements and the programme's rigorous internal assessment requirements (IBO, 2015a, p 4).

The knowledge, skills and attitudes that students develop through the MYP science courses provide a meaningful foundation for further study and help to prepare students for careers in academic and corporate research, as laboratory assistants and managers, in scientific consultancy for a range of companies and NGOs, in teaching, in fieldwork and journalism, thereby making them "college and career ready" and prepared for careers in science as emphasized by the NGSS.

MYP and the scientific and engineering practices (SEP) of the NGSS

"The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose." (NRC, 2012, p 73)

Within the IB continuum (PYP, MYP and DP), the MYP seems to be the best fit for accommodating the scope and depth of science education as demanded by the NGSS. The striking similarities between the MYP design cycle and the "Three spheres of activity for scientists and engineers" (NRC, 2012, p 60) as represented by the NRC are evident below.

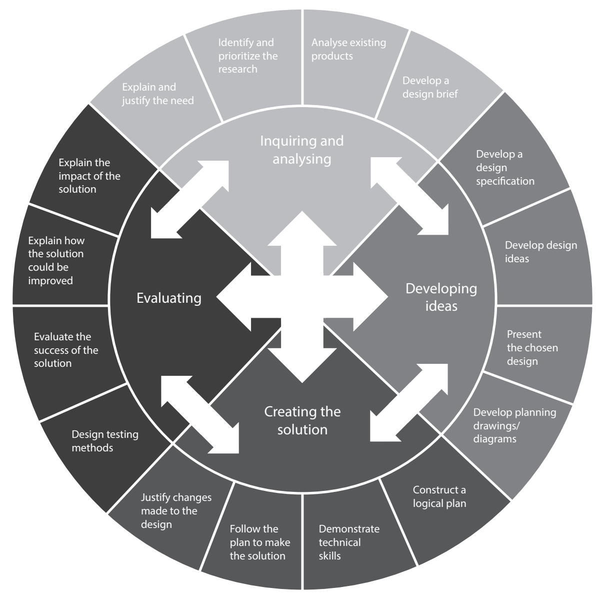

Figure 13a: The MYP design cycle

The MYP design cycle complements the "cycle of research and design" that is at the centre of a STEM-based approach to learning, engineering and design. The eight standards for mathematical practices in grades 6 to 10 of the MYP also offer numerous possibilities for integrating the engineering, design and technology elements of the NGSS in terms of content, concepts and scientific practices.

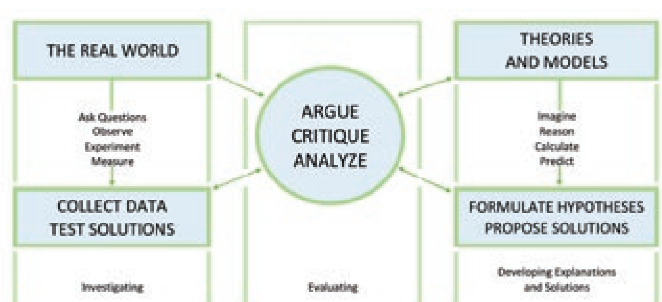

Figure 13b: The three spheres of activity for scientists and engineers—A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Academies Press, 2012)

Building on the aims of MYP mathematics to help students "develop powers of generalization and abstraction", schools will be able to develop the conceptual synergy between mathematics and the sciences while meeting the rigour of the engineering and design practices within the NGSS. Thus, the MYP offers immense possibilities for incorporating the NGSS through inquiry-based, authentic learning projects to integrate engineering, design and technology.

The MYP global contexts offer immense potential for explorations that create additional contexts for teaching and learning in mathematics and sciences. These explorations also invite inquiry from other subject groups into scientific and mathematical contexts. All teachers in the programme are also encouraged to develop additional global contexts and authentic explorations that explore subject-specific settings, events or circumstances (IBO, 2014).

Global context	Example explorations
Identities and relationships	Possible explorations to develop: • Mathematical identities, modelling versus reality, equations and variations, the mathematics of epidemics on social media • Relationships—causation and correlation (including spurious correlations) • Data management, what "big data" tells us about ourselves • Financial literacy • Anthropometry
Personal and cultural expression	Possible explorations to develop: • Science in national communities; science and communities of faith and personal beliefs • The historic development of the periodic table • Calendars and timekeeping
Scientific and technical innovation	Possible explorations to develop: • Rapid prototyping and 3D printing • Genetic mutation and modification • Human microbiomes and personalized medicine • Citizen science and crowd-sourced data
Globalization and sustainability	Possible explorations to develop: • Design and scale • Food—ethics, access, printing, security, synthetics and counterfeiting • Scarcity of resources (rare earth metals, helium, resource scares) and green technology
Fairness and development	Possible explorations to develop: • Land management, resource allocation and access • Ecology and impact • Fairness in games of chance, data-driven decisions • Mathematical indices of development and human capabilities
Orientation in space and time	Possible explorations to develop: • Indigenous understanding—astronomy, biodiversity erosion • Mensuration and standardization, gravity maps • The geometry of "unbuilt" cities, crowd-sourced cartography, the role/reliability of simulations

Figure 14: MYP global contexts—possible explorations

Besides the traditional science courses of biology, chemistry and physics, MYP schools can choose to offer and develop other courses such as:

- environmental sciences
- life sciences
- physical sciences
- sport sciences
- health sciences
- earth sciences. (www.ibo.org)

The range of subjects available for study in the MYP also provides the required breadth to incorporate the NGSS with rigour and depth. However, since most US high schools (grades 9 and 10) offer the various options in the sciences as electives, the time factor in terms of addressing the depth and rigour as demanded by the NGSS may pose some challenges as it does in the PYP.

In terms of assessment, MYP assessments and ePortfolios do seem to offer the required scope and potential. Needless to say, this will also involve an investment of time in terms of planning and collaboration. However, in light of the points above, the possibility of incorporating the NGSS within the MYP seems both feasible and sustainable.

Diploma Programme

The DP, with its focus on preparing students for university, brings some interesting opportunities as well as challenges in implementing the NGSS. The content-heavy, assessment-oriented DP offers less flexibility in terms of both curriculum design and pedagogical approaches. Misconceptions among teachers regarding how an inquiry-based, concept-based approach can help deliver subject-specific content to secondary students remain a challenge for DP teachers.

However, within these challenges, it needs to be acknowledged that the "college and career readiness" that both the DP and the NGSS seek to achieve through intellectual rigour and 21st-century knowledge, understanding and skills are complementary. While the NGSS describe the scientific skills and knowledge all students should be able to demonstrate upon graduation from 12th grade, the standards do not prescribe the course content or curriculum that students should follow to meet these performance goals. The DP curriculum in this sense provides the potential and a viable route to achieve these goals. This will, however, call for a careful and critical rethinking of not only DP science coursework, but also other opportunities that enable the STEAM-based (Science, Technology, Engineering, Arts and Mathematics) approach that the NGSS demands.

Since the DP is for students in the 11th and 12th grades while NGSS high school performance expectations reflect expectations at the end of high school, educators, schools, and districts will need to carefully design course pathways and content within courses to ensure that all NGSS high school performance expectations are assessable by the end of the 12th grade. This requires careful reconsideration of both the content of IB courses students may take for the DP, as well as other science courses students may have taken in high school (grades 9–12). Within a given DP science course, there may be several opportunities for students to demonstrate proficiency in certain NGSS performance indicators. However, a systematic and rigorous approach in assessing the proficiency of DP students through the performance indicators will require purposeful and strategic modifications to how an IB educator currently envisions or delivers a course. Students (and subsequently all stakeholders such as parents, teachers, counsellors and administrators) will need to be supported in thinking through their course selection relatively early in their secondary school science experiences (middle school or very early in high school) to ensure that their high school experiences reflect both the NGSS and IB requirements.

Correlation and congruence through mutually supportive goals

The NGSS articulates the knowledge, understanding and skills that students need to demonstrate proficiency in by the end of the 12th grade. The NGSS strive to achieve this across four primary science domains: life science, physical science, Earth and space science, and engineering design.

High school expectations build on knowledge and skills developed in K–8, and high school science is expected to provide the capstone experiences of a coherent science learning progression across all disciplines. The NGSS are designed to be rigorous, practical, and ensure that students have sufficient knowledge and skills across science domains, science and engineering practices, and crosscutting concepts to be successful in post-secondary endeavours.

The approach of the DP, particularly within the group 4 courses, is supportive of the goals of the NGSS. The primary DP courses that support the goals of the NGSS are outlined below.

Biology SL: A standard level course designed for all students, intended to provide a survey of the study of life and its structures, processes, dynamics, and behaviours, ranging from the microscopic interactions and activities of cells to the macroscopic dynamics of populations and ecosystems.

Physics SL: A standard level course designed for all students, intended to provide a survey of the experimental models and theories of physics, ranging from sub-atomic particle interactions to the dynamics of vast systems.

Chemistry SL: A standard level course designed for all students, intended to provide a survey of the study of chemical sciences.

Environmental systems and societies SL: An interdisciplinary subject that combines knowledge across experimental and social sciences to provide students with a coherent perspective of the interrelationships between environmental systems and societies.

(Note: HL components of each of these courses (except for environmental systems and societies which does not have an HL offering at this time) are also supportive of the goals of the NGSS, but ask students to engage in some topics in greater breadth and depth.)

These DP courses represent the breadth and depth within each discipline. It is important to note that while it is likely that a DP student will take a single science course through one of these disciplines (and at most two) over the course of the two-year programme, the NGSS (that require students to demonstrate proficiency in all performance expectations) will need to be embedded within and across all of the sciences. Because DP science courses have detailed curriculums, aims and objectives, it is possible to begin thinking about how DP courses may help students meet some of the NGSS performance expectations.

It needs to be acknowledged that it is highly unlikely that schools in the dual implementation will devote more time for science learning than that required for the DP. The balance here needs to be brought about by highlighting the IB philosophy of depth versus breadth. In this sense, although the core science concepts explored within the sciences in the DP may be limited, they strive towards developing scientific ways of thinking which will provide the students with the knowledge, understanding and skills to further develop analytical skills for the scientific and engineering process and ways of thinking that can be applied to explore new science concepts. When considering alignment in this way, it may be helpful to think about the following key points.

What are the targeted performance expectations (or parts of performance expectations) for which students will be able to demonstrate proficiency by the end of a given course? Student performance expectations in the NGSS require proficiency across three dimensions: science and engineering practices, disciplinary core ideas, and crosscutting concepts. When thinking about alignment, it is important to consider to what extent students will have the opportunity to engage in all aspects of a targeted performance expectation within a selected course. If a performance expectation will not be met, careful consideration should be given to what course and in what context students will have the opportunity to engage with that material, so that they will be able to demonstrate proficiency in the performance expectations by the end of high school.

Are there certain student experiences, or types of experiences, that would be necessary for reaching NGSS targets within a course, that are not specifically dictated by the IB curriculum? It is possible that some NGSS performance expectations may be addressed within the IB curriculum given a certain set of experiences, for example, a series of research projects viewed through a particular lens; a specific context or phenomenon used to ground student experiences and encourage certain proficiencies; a change in approach to how students learn certain content (exploring science concepts through investigations and data analysis as emphasized by the IB). Since both NGSS and the IB place equitable access to science for all students as paramount, it is imperative that any such nuances be carefully considered.

Within a given discipline (life science, Earth and space science, physical science, engineering), the performance expectations that are not met by a DP course in that discipline also need to be identified. Since IB science courses are largely discipline-specific, it will be important to know whether a full set of performance expectations can be met by a DP course, as this may have implications for student coursework in earlier years. For example, if a student takes an IB biology course in 11th grade, will they be able to complete all the life science performance expectations described in the NGSS? If so, students may plan to take a physical science course and Earth/space science course in 9th and 10th grade, assuming those courses similarly meet all the performance expectations in those disciplines. Alternatively, if all the life science performance expectations would not be met in a single biology course, will students have the opportunity to meet them through other work in the 9th and 10th grades, through discipline-specific or integrated science courses? How many courses would be necessary? This may also have implications for science course design in 9th and 10th grades.

The opportunity for an integrated engineering experience in the science courses within the DP needs to be solidified. Since the NGSS expect that students develop proficiency in engineering skills and knowledge through application with science, it is important to ensure that students have continued and consistent access to this integrated approach both in DP science courses, and in other science courses students take during high school.

There is indeed an overlap between the content covered in specific science courses offered in the DP and some NGSS performance indicators. However, the overlap is unlikely to be complete for single courses, and there are gaps between content covered in NGSS disciplines and IB courses that might seem "equivalent" (for example, NGSS high school life sciences and DP biology). As a result, the NGSS performance expectations that students would be able to demonstrate proficiency in as a direct result of DP sciences upon graduation vary greatly, depending upon the science courses the student would have chosen to take, both in the DP as well as in earlier years.

Additionally, there are broader issues to consider. For example, DP sciences strongly incorporate life and physical sciences, but do not reflect Earth and space science as deeply. This calls for Earth sciences to be explored through geography as well as environmental sciences.

While there seem to be immense possibilities to explore Earth and space sciences in both the PYP and the MYP, the DP does not seem to embrace this component of the NGSS. For instance, the PYP's transdisciplinary theme of "How the world works" offers immense potential for learners to deeply understand environmental systems and the importance of the Earth's non-renewable resources. Thereby it also promotes action to conserve natural resources. All of this helps meet the performance expectations as outlined in the Earth and space sciences domain within the NGSS.

However, it could be argued that although the DP sciences strongly incorporate life and physical sciences, they do not reflect Earth and space science as deeply and as effectively. Nevertheless, this can be approached through multiple pathways in the DP. The environmental systems and societies (ESS) course (currently being offered as SL) and the geography course (although technically not falling under "IB sciences") offer immense potential for the active engagement and meaningful exploration of the Earth and space sciences within the DP.

Environmental systems and societies, one of two interdisciplinary courses offered in the DP (thereby enabling students to choose this course as either a group 3 or group 4 subject), requires students to evaluate the scientific, ethical and socio-political aspects of various issues.

"The interdisciplinary nature of the DP course requires a broad skill set from students, including the ability to perform research and investigations, participation in philosophical discussion and problem-solving. The course requires a systems approach to environmental understanding and promotes holistic thinking about environmental issues". (IBO, 2015b)

Through hands-on work (in the laboratory or fieldwork, both align to the vision of the NRC's framework of science education), the DP environmental systems and societies course offers immense potential for creating awareness about local and global environmental concerns and at the same time developing an understanding of the scientific methods, investigations and practices that help demonstrate proficiency in the NGSS performance indicators.

While the external examination component of environmental systems and societies offers students the opportunity to "demonstrate an understanding through the application, use, synthesis, analysis and evaluation of environmental issues, information, concepts, methods, techniques and explanations", the internal assessment component "comprised of a series of practical and fieldwork activities enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations". (IBO, 2015c)

The DP geography course is highly conceptual in nature (compared with traditional geography courses that require rote memorization of discrete facts and figures) and aims to provide an overview of the geographic foundation for the key global issues of our time. Through a "synergistic" approach of factual and conceptual engagement, the course provides the opportunity to explore topics concerning poverty reduction, gender equality, improvements in health and education, and environmental sustainability.

For instance, the paper 1 component of DP geography, explored through the core conceptual themes of "patterns and change" and the factual (compulsory) topics of "patterns in environmental quality and sustainability" and "patterns in resource consumption", not only offers immense potential to incorporate the relevant NGSS crosscutting concepts but also to explore the Earth and space sciences through meaningful and sustained inquiry.

"The performance expectations in ESS3: Earth and Human Activity help students formulate an answer to the question: "How do Earth's surface processes and human activities affect each other?" The ESS3 Disciplinary Core Idea from the NRC Framework is broken down into four sub-ideas: natural resources, natural hazards, human impact on Earth systems, and global climate change. Students understand the complex and significant interdependencies between humans and the rest of Earth's systems through the impacts of natural hazards, our dependencies on natural resources, and the significant environmental impacts of human activities". (Achieve, 2013, p 2)

The core themes of DP geography, in combination with the optional themes of paper 2 and the extension components of paper 3 (global interactions), offer many pathways to meaningfully explore the NGSS Earth and space sciences:

Some paper 2 optional themes that are applicable in this context include the following:

- Freshwater—issues and conflicts
- Oceans and their coastal margins
- Extreme environments
- Hazards and disasters
- The geography of food and health
- Urban environment

"For the purpose of the NGSS, biogeology has been addressed within the life science standards. Students develop models and explanations for the ways that feedbacks between different Earth systems control the appearance of Earth's surface. Central to this is the tension between internal systems, which are largely responsible for creating land at Earth's surface, and the sun-driven surface systems that tear down the land through weathering and erosion. Students begin to examine the ways that human activities cause feedbacks that create changes to other systems". (Achieve, 2013, p 1)

How the above can be correlated and embedded within DP geography is evident from some of the HL extension components identified below.

- Environmental change
- Global interactions at the local level

While these pathways offer some specific ways to explore the Earth and space sciences within the DP, a holistic consideration of the other components of the DP such as theory of knowledge and the extended essay as well as DP courses such as computer science, design technology and information technology in a global society (ITGS) will reveal immense possibilities for meaningful and unconventional ways through which students can be prepared for IB high-stakes assessment as well as be fully prepared for meeting the NGSS performance expectations. In some cases, this may also mean additional content needs to be incorporated into students' secondary science learning.

The extended essay, including the world studies option, is a compulsory, externally assessed piece of independent research. Presented as a formal piece of scholarship containing no more than 4,000 words, the aims of the extended essay are to provide students with the opportunity to pursue independent research on a focused topic, to developing creative and critical thinking skills through reasoned argument, and to apply appropriate analytical and evaluative skills, leading to the opportunity of experiencing the excitement of intellectual discovery (IBO, 2014c).

It is also important to recognize the high level of flexibility the NGSS afford educators and students in terms of meeting the standards. Although some creativity in approach and restructuring of instruction or internal assessments may be necessary, the mutually supportive goals and intents of the DP and the high school NGSS performance expectations suggest a promising road ahead, although it may not be devoid of challenges.

As a quick example, figure 15 gives an overview into one possible arrangement of components and highlights both the opportunities and challenges arising from this approach.

It needs to be acknowledged that while it is very possible to meaningfully integrate NGSS requirements within the DP science courses currently available, this is more teacher-dependent rather than a course requirement, which can result in gaps and inconsistencies in the way these are interpreted and implemented. This, when combined with the logistical challenge of high school teachers being departmentalized, will necessitate new ways of fostering interdisciplinary thinking and curriculum planning in the DP.

Topic	1: Measurements and uncertainties	2: Mechanics	3: Thermal Physics	4. Waves	5. Electiricty and magnetism	6. Circular motion and gravitation	7. Atomic, nuclear, and particle physics	8. Energy production	No explicit connection
		HS-PS2-1	HS-PS3-4	HS-PS4-1	HS-PS2-5	HS-PS2-4	HS-PS1-8	HS-PS3-1	
		HS-PS2-2	HS-PS3-2		HS-PS3-5	HS-ESS1-4		HS-PS3-2	HS-PS2-6
		HS-PS2-3			HS-PS3-3			HS-PS3-3	
		HS-ETS1-2*			HS-ETS1-1*			HS-ETS1-1*	HS-PS4-2
		HS-ETS1-1*							

11. Electromagnetic Induction (AHL)	12. Quantum and nuclear physics	Option D- Astrophysics
HS-PS4-3	HS-PS4-4	HS-ESS1-1
HS-PS4-5		HS-ESS1-2
		HS-ESS1-3

Figure 15: Content overlap between the DP and NGSS

DP and the scientific and engineering practices (SEP) of the NGSS

Realistically the engineering, design and technology aspects of the NGSS also call for the integration of science, mathematics, economics, sociology, anthropology and technology. Therefore the DP will need to consider how this integration can be implemented in the programme to provide the base for a rigorous and sustainable integration of the NGSS. Much of this can be achieved by making the necessary alignment when DP courses undergo their cyclical seven-year reviews.

Science and engineering practices in high school

The science and engineering practices (SEPs) in the NGSS represent the knowledge and skills associated with scientific investigations and problem-solving that students are expected to know and be able to use by the end of the 12th grade. These practices, including what they are and why they are important, are described in the framework as a mechanism to "help students understand how scientific knowledge develops ... and understand the work of engineers, as well as the links between engineering and science". Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply. The term "practices" is used, rather than "skills" or "inquiry" "to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice" (NRC, 2012).

The NGSS provide detailed explanations of what these expectations look like at each grade band (Appendix F) and can help in providing a framework for identifying the relationship between similar goals for DP students.

General overlap between scientific and engineering practices of the NGSS and DP aims

It is important to note that any single practice is connected to other practices, and may have overlapping features, therefore, it is likely that several practices will bear a relationship to any given feature of the DP. Moreover, the practices represent ways for students to both develop and demonstrate their understanding of science and engineering, and as such can serve as both the indicator of student progress as well as the mechanism by which students develop their understanding. This means that many practices will be related to a given group 4 aim or assessment objective, but they each represent an important set of skills and knowledge that students should develop.

Because the practices all represent different ways students can demonstrate their thinking, as well as knowledge and skills, certain DP aims either relate to the practices as a whole or are emergent in student reflection about their experiences across all practices. These include:

- Appreciate scientific study and creativity within a global context through stimulating and challenging opportunities
- Acquire a body of knowledge, methods, and techniques that characterize science and technology
- Apply and use a body of knowledge, methods, and techniques that characterize science and technology
- Become critically aware, as global citizens, of the ethical implications of using science and technology
- Develop an appreciation of the possibilities and limitations of science and technology

While these are certainly related to some individual practices in important ways (detailed in the following sections when appropriate), in general, these apply to all the practices collectively.

Additionally, all practices offer students the opportunity to "demonstrate their knowledge and understanding of" and "apply" methodologies, techniques, and concepts. Like the selected aims discussed previously, there are some instances in which these assessment objectives have a particular relationship with a specific practice (which are detailed as appropriate detailed in the following sections). However, there are also assessment objectives that are related to all practices.

Science and engineering practices—asking questions and defining problems

"Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution." (NRC, 2012, p 56).

In high school, students focus on formulating, evaluating, and refining empirical questions, and defining addressable problems using models and simulations. Students consider increasingly complex phenomena and systems, and ask questions that clarify and probe sophisticated relationships, models and explanations. Students ask questions based on evidence and logical, scientific reasoning, allowing students to demonstrate their understanding of core ideas and broad concepts by critically probing explanations, arguments, evidence, and claims. Similarly, students define problems—including criteria, constraints, and the system within which the problem and solution are embedded—based on evidence, reasoning, and application of scientific and engineering ideas.

Crosscutting concepts in the DP

In the NGSS, the crosscutting concepts represent ideas that can be used to connect knowledge and thinking across science disciplines. These are specific to science, but many of the crosscutting concepts have broader applicability to other subject areas. As part of the DP, crosscutting concepts in science courses may provide students with explicit tools to connect their knowledge and understanding in science not only with other sciences, but to other topics and global contexts as well.

One of the reasons that the crosscutting concepts are an innovation of the NGSS is not because they have not been present in science education previously, but because they have traditionally been implicit components of science education rather than explicit knowledge that students develop and apply with the express intention of providing cognitive frameworks for students to organize their thinking. As a complete programme, the DP supports a curriculum that engages students in broad conceptual understanding and the interconnectedness of knowledge across subject areas. Deep understanding and application of the crosscutting concepts, like the other dimensions, straddles both scientific understandings as well as application to explain phenomena.

In addition to specific courses (for example, environmental systems and societies) and expectations within specific courses that directly tie with some elements of the crosscutting concepts, the nature of science in the DP provides some tangible connections to the crosscutting concepts, and is also supportive of the knowledge underlying many of the science and engineering practices. In the NGSS, there are seven identified crosscutting concepts, each with several elements that students are expected to know and apply by the end of high school which are explained in the following sections.

Patterns

"In grades 9–12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their

explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system."

Identifying and interpreting patterns from surrounding chaos is central to furthering scientific and engineering endeavours, and is closely linked to concepts and practices of science, such as identifying, using, and evaluating evidence and reasoning, analysing and interpreting data, and asking questions. Because of the experimental approach of DP sciences and the emphasis on data analysis, evidence and application to phenomena, DP sciences can offer rich opportunities for students to develop and use this crosscutting concept in increasingly sophisticated ways. Specifically, some elements of the nature of science in the DP that specifically highlight the objectivity of science are very closely linked to patterns as a crosscutting concept.

The DP supports student understanding of both quantitative and qualitative patterns. "Scientists analyse data and look for patterns, trends, and discrepancies, attempting to discover relationships and establish causal links. This is not always possible, so identifying and classifying observations is still an important aspect of scientific work." (IBO 2016, *Biology guide*, p 4)

Cause and effect

"In grades 9–12, students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects."

The NGSS places a great emphasis on the relationship between evidence, cause, correlation, and reasoning. This crosscutting concept is closely related to many other concepts and practices in the NGSS, making understanding and applying ideas around cause and effect central to students' science endeavours.

Systems and system models

"In grades 9–12, students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g. physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks. "

Scale, proportion, and quantity

"In grades 9–12, students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g. linear growth vs. exponential growth)."

Energy and matter

"In grades 9–12, students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and

another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved."

Structure and function

"In grades 9–12, students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. They infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials."

The crosscutting concepts do not "correlate" with the composition of DP courses, but rather are more generally and holistically supported by the approach of the DP. For this reason, DP science teachers will need to pay special attention to developing this knowledge and these skills explicitly in their DP science curriculum. The crosscutting concepts can be very powerful tools for making important aspects of the DP, such as nature of science and connections to the practices and application of science, explicit and rich in learning opportunities for students. The crosscutting concepts can also be very helpful to teachers when planning units of instruction and goals within lessons and units, as well as for crafting meaningful scenarios and phenomena for students to engage in. In this way, crosscutting concepts and elements of the DP can be useful and mutually supportive tools for both teachers and students alike. (See NGSS Appendix G for a complete guide to the crosscutting concepts expectations).

Disciplinary core ideas—overlap in the DP

To help educators identify areas of overlap between DP courses, here we describe some high level congruence and divergence among the expectations within each NGSS discipline and similar DP course. Educators should conduct their own analyses with their specific curriculum in mind, as that will provide a more detailed sense of overlap, gaps, and how it may be possible to address these gaps.

Core ideas in NGSS high school life science:

- From molecules to organisms: structures and processes
- Ecosystems: interactions, energy, and dynamics
- Heredity: inheritance and variation of traits
- Biological evolution: unity and diversity

Core ideas in NGSS high school physical science:

- Matter and its interactions
- Motion and stability: forces and interactions
- Energy
- Waves and their applications in technologies for information transfer

Core ideas in NGSS high school Earth and space science:

- Earth's place in the universe
- Earth's systems
- Earth and human activity

The DP expectations and guides are structured quite differently from the NGSS, and with good reason. The NGSS lists performance expectations that are snapshots of student performance indicative of a wide range of knowledge and skill that students have accrued over instructional experiences. Every NGSS performance expectation asks students to use a wide range of experiences across practices, crosscutting concepts, core ideas, metacognitive and reflective ideas, and different situations in order to meet it. The DP, unhindered by the need for standards statements, can expand upon the goals, approach, and resulting attributes students should possess.

Research suggests that a concept-based approach to curriculum and instruction offers much value not only in secondary education, but also at university level and beyond (see for example, Mazur (1997) on teaching introductory physics at Harvard; Chappell and Killpatrick (2003) on teaching AP calculus at Michigan State University, Hadjerrouit (2009) on teaching and learning informatics, etc.). Giddens (2007) argues that the ever-growing body of knowledge in the field of medicine poses new challenges in the training of nurses and that only through a concept-based approach to curriculum and instruction can we rescue pre-service nursing education from its current situation of "content saturation". If so, then why is secondary education currently unable to meet such needs?

Through an interesting anecdote Mazur (1997), who teaches introductory physics at Harvard University, highlights how students' conceptions (and misconceptions) are often excluded from science instruction in higher grades:

"Professor Mazur, how should I answer this question? According to what you taught us, or according to the way I usually think about these things?"

Mazur further notes that though the audience and the requirements from universities have changed over time, many courses (even at the university level) have not changed much, both in terms of the approach and the material:

"The way physics is taught in the 1990s is likely not much different from the way it was taught—to a much smaller and more specialized audience—in 1890...Physics has become a building block for many other fields including chemistry, engineering and life sciences. As a result, the enrollment in physics courses has grown enormously, with the majority of students not majoring in physics... While traditional methods of instruction have produced many successful scientists and engineers, far too many students are unmotivated by the conventional approach. What, then, is wrong with the traditional approach to introductory physics?"

Fifty years after its inception in 1968, the DP needs to look at making the programme more interdisciplinary than it currently is. A good starting point could be the extended essay, for instance.

The continual process of reflection and improvement that the IB engages in to meet the dynamic needs of the 21st century is noteworthy in this context. Previously, for instance, interdisciplinary approaches and topics such as biotechnology were explicitly discouraged as topics for the extended essay (Doherty, 2010), perhaps because teachers did not have the expertise to supervise such a cross-disciplinary topic. However, the inclusion of topics such as nanotechnology within the MYP (see appendix) is clearly an indication that the IB is already well on its way to being able to equip students with the knowledge, understanding and skills needed in such Science Technology Engineering Mathematics (STEM) integration explorations.

Although in terms of curriculum and instruction the DP requires deep conceptual engagement fostered through an inquiry-driven approach, the end of course paper-based assessments continue to inform and shape classroom instruction as this accounts for a major percentage of student grades in the programme. Even though the group 4 project in the sciences allows for exploration and the opportunity to engage in scientific practices, the project currently carries zero weighting in the assessment. This highly student-centred, real-world application-based project is compulsory for all students studying a group 4 subject, regardless of course or diploma status, however, it does not currently contribute to a final grade. There is, however, huge potential in the group 4 project to meaningfully incorporate the NGSS within the DP. The DP assessments need to be reconsidered in a way that they provide sufficient scope and opportunities to integrate engineering, design and technology aspects through content, concepts and scientific practices.

It is also important to bear in mind that while planning the engineering, design, technology aspect of the science curriculum, the three dimensions of the NGSS (science and engineering practices, crosscutting concepts, and disciplinary core ideas related to engineering) need to be considered together to see how engineering is represented as a whole, in a "synergistic" fashion (Erickson, 2008). This will require science and mathematics teachers to plan the scientific inquiry together, since engineering, as interpreted in the NGSS, includes science and mathematics content, concepts and understanding. (Matrices of crosscutting concepts and disciplinary core ideas are available in appendix 1).

"Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question." (NRC, 2012, p 65)

To effectively integrate the NGSS within the DP science curriculum, secondary teachers not only need to plan together, but also need to team-teach. Interdisciplinary and transdicsiplinary teaching, the hallmark of IB education (particularly in the PYP and the MYP), needs to be emphasized in the DP as well. Conceptually, the DP requires students to draw upon the knowledge and understanding of various disciplines (particularly in theory of knowledge and the extended essay). However, purposeful and consistent lesson planning through interdisciplinary approaches that help permeate into meaningful interdisciplinary teaching and learning (in the same model that the teachers of PYP and the MYP follow) needs to be established within the DP as well.

Assessments in the IB and performance expectations in the NGSS

It is essential to keep in mind that the fundamental difference between the IB and the NGSS does not come from a mismatch in philosophies of student learning, but rather from the fact that the purpose of IB assessment and the NGSS performance indicators are different. The NGSS does not provide a "qualification" in the sense that the IB assessment does. The NGSS performance indicators can inform and add value to the already existing holistic nature of IB assessment, but keep in mind that the IB strives for comparability and consistency of measurement as the key focus of IB assessment.

Bear in mind while reading this report (particularly, this section of the report) that the goal is to see how the NGSS student performance indicators fit within the overarching IB assessment philosophy, which already inculcate what the NGSS demand (and perhaps in most instances go beyond that). However, the key question and challenge is how each school engaging in the dual implementation can ensure students in the IB programme have the opportunity to demonstrate proficiency over the NGSS performance indicators.

The NGSS philosophy, that all students should be provided with a wide range of learning engagements through which they can demonstrate their understanding of the performance expectations, deeply resonates with the IB philosophy. Activities that reflect science learning in the IB include:

- developing and refining models
- generating, discussing, and analysing data
- engaging in both spoken and written explanations and argumentation
- reflecting on the student's own understanding.

The NRC (2014, p 3) highlights that the learning engagements designed to assess the performance expectations in the NGSS will need to have the following characteristics (Conclusion 4–1):

- include multiple components that reflect the connected use of different scientific practices in the context of interconnected disciplinary ideas and crosscutting concepts
- address the progressive nature of learning by providing information about where students fall on a continuum between expected beginning and ending points in a given unit or grade
- include an interpretive system for evaluating a range of student products that are specific enough to be useful for helping teachers understand the range of student responses and provide tools for helping teachers decide on next steps in instruction.

In terms of assessments, the IB notes that every school needs to have systems in place to ensure that **all students** can demonstrate a consolidation of their learning through the completion of the PYP exhibition, the MYP personal project (or community project for programmes that end in MYP year 3 or 4), the DP extended essay and the IBCC reflective project, depending on the programme(s) offered (IBO, 2014).

Teachers in the IB programmes need to engage in purposeful and critical analysis of how this will impact both the assessment for learning (formative assessment) and assessments of learning (summative assessment) within the IB programmes. Summative assessments are aimed at determining the level of achievement of a student, generally at the end of a course of study (in the DP), and formative assessments are aimed at identifying the learning needs of students and form part of the learning process itself (IBO, 2004, p 3).

In this sense, the constructivist philosophy fostered through classroom discussions and practised in IB classrooms (across the continuum) becomes a critical component of formatively assessing the NGSS performance expectations. As noted by the NRC (2014, p 95), formative assessments:

"provide a way for students to engage in scientific practices and for teachers to instantly monitor what the students do and do not understand. That is, the assessment, which is intended to be formative, is conducted through the teacher's probing of students' understandings through classroom discussion. The discussion shows how students engage in several scientific and engineering practices as they construct and defend their understanding about a disciplinary core idea".

In terms of summative assessments, teachers will need to recognize that while some assessments may provide the opportunity for students to demonstrate mastery over more than one performance indicator, other instances may call for more than one assessment task to be conducted to demonstrate adequately the mastery of one performance indicator. Assessing the disciplinary core ideas and scientific practices may also require the same to be assessed in more than one disciplinary context (NRC Conclusion 2–4, p 46). Such opportunities also form the basis for the development of assessments of three-dimensional science learning. As given below, the approaches to learning (ATL) skill categories mapped with the MYP skill clusters, juxtaposed with the NGSS bring forth the alignment with much clarity:

ATL skill categories	MYP skill clusters
Communication	I. Communication
Social	II. Collaboration
Self management	III. Organization
	IV. Affective
	V. Reflection
Research	VI. Information literacy
	VII. Media literacy
Thinking	VIII. Critical thinking
	IX. Creative thinking
	X. Transfer

Figure 16: A comparison between ATL skill categories and MYP skill categories

Although it is acknowledged that assessment across the IB continuum offers the scope and flexibility to incorporate the NGSS in multiple ways, it is also acknowledged that consistent and effective integration of three-dimensional science learning will require "more than a one-to-one mapping between the performance expectations and assessment tasks" (NRC Conclusion 2–4, p 46). What may also be required is a systematic evaluation of the current assessment practices within the IB programmes in order to highlight the pragmatic challenges associated in integrating the NGSS performance expectations within IB assessments.

The approach of "three-dimensional science learning" (NRC, 2012, p 123) recommended by the NGSS refers not only to the process of learning that happens through the integration of these dimensions, but also to the kind of "thinking and understanding that science education should foster". It also calls for the integration of classroom practices that make "thinking visible"—the opportunity for teachers and students to see through the process of how learning occurs—during the learning engagements.

More broadly, a system of assessments will be needed to measure the NGSS performance expectations and provide students, teachers, administrators, policy makers, and the public with the information needed about student learning (NRC Conclusion 6–1).

The development of scientific ideas is not a linear process. Scientific ideas are generated through an iterative refinement of inquiries and ideas through which evidenced-based reliable knowledge of the world is built. The synergistic and iterative process of scientific inquiry as proposed by both the IB and the NGSS is demonstrated in figure 17.

To develop the skills and dispositions required to use scientific and engineering practices to further their learning and to solve problems, students need to experience instruction in which they:

- use multiple practices in developing a particular core idea
- apply each practice in the context of multiple core ideas.

Effective use of the practices often requires that they be used in concert with one another, such as in supporting explanation with an argument or using mathematics to analyse data (NRC Conclusion 4–2).

The following sections analyse the implication of this approach within the assessment component of each of the IB programmes.

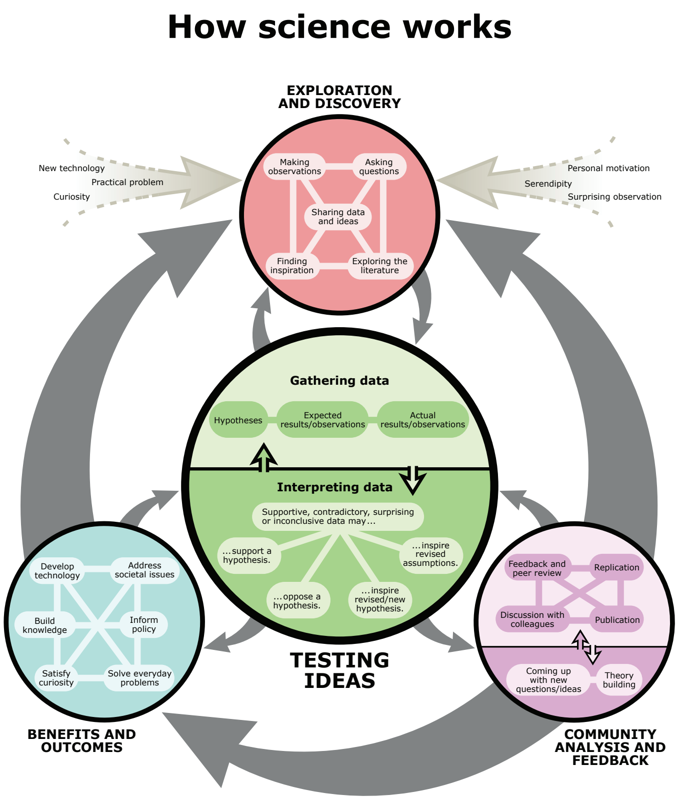

Figure 17: Science flowchart (Understanding science, 2016)

Assessment in the PYP and the NGSS

The PYP philosophy that science education is characterized by concepts and skills rather than just the content complements the three-dimensional approach promoted by the NGSS. According to the PYP assessment philosophy:

"Assessment is the gathering and analysis of information about student performance. It identifies what students know, understand, can do and feel at various stages in the learning process." (IBO, 2007)

Since all science learning in the PYP takes place within the framework of the six transdisciplinary themes, a useful approach to integrating the NGSS would be to map PYP transdisciplinary themes to the disciplinary core ideas from the NGSS. The knowledge and the application of science, enhanced by inquiries into the central ideas as defined by the transdisciplinary themes, provide a holistic approach to science education within the PYP.

The knowledge component of science in the PYP explored through the four strands—living things, Earth and space, materials and matter, forces and energy—offers immense potential to incorporate and assess the disciplinary core ideas articulated by the NGSS—the physical sciences; the life sciences; the Earth and space sciences; and engineering, technology and applications of science. Using the NGSS evidence statements as starting points to design PYP summative assessments could also be a useful strategy.

Students in the PYP are provided with a wide range of opportunities to demonstrate their knowledge and understanding. These include, but are not limited to, portfolios, quizzes, presentations, role plays, tests, interviews, reflection journals, class discussions, debates, and the culminating PYP exhibition (all of which are school-based and designed by teachers). The PYP also lays significant emphasis on exploiting occasions that present themselves for student-initiated spontaneous science inquiries (IBO, 2011, p 10).

As noted by the NRC (2012, p 91), to teach toward the NGSS performance expectations, teachers will need a sense of the likely progression at a more micro level, to answer such questions as:

- For this unit, where are the students expected to start, and where should they arrive?
- What typical intermediate understandings emerge along this learning path?
- What common logical errors or alternative conceptions present barriers to the desired learning or resources for beginning instruction?
- What new aspects of a practice need to be developed in the context of this unit?

While teachers are brainstorming the anticipated teacher questions or provocations when developing a PYP unit of inquiry and the programme of inquiry, some questions can specifically be targeted towards addressing and incorporating the standards. Teacher questions serve as an opportunity for teachers to model inquiry for students. Articulating teacher questions in this manner in the unit of inquiry and the programme of inquiry also facilitates the vertical and horizontal alignment of the written, the taught, and the assessed curriculum.

"Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution." (NRC, 2012, p 56).

The student questions or provocations then serve as the starting point of scientific investigations that embed the engineering design practices of the NGSS. (A typical example of how this has been developed by a group of grade 3 teachers in the PYP is available in appendix 2).

The NGSS performance indicators being articulated as grade bands (K–2, 3–5 and so on) offers the possibility for PYP teachers to plan and implement the standards within the elements of the PYP framework in a two-year time period. This level of flexibility might prove very useful as it helps to take into account local and school-related contingencies while engaging in the dual implementation of the IB and the NGSS. Mapping the NGSS grade-level performance expectations against the PYP scope and sequence documents could be another useful approach in vertical and horizontal articulation of both the taught and the assessed curriculum.

Assessment in the MYP and NGSS

The MYP emphasizes the need to organize learning in a way that students will become increasingly aware of the connections between subjects, content and the real world. Through a wide range of assessments (both school-based and examinations, summative via eAssessments), students are given ample opportunities to demonstrate proficiency against criterion-referenced assessment indicators leading to the MYP Certificate and school-based records of participation. The school-based assessments within the MYP (for years 1–3 of the programme) and the external examinations (for years 4 and 5 of the programme) help to bring about breadth, balance and rigour in the assessments.

Scientific investigation through analytical and critical thinking promoted through an inquiry-based approach offers immense potential to assess not only the disciplinary core ideas, but also the scientific and engineering practices of the NGSS. The MYP science framework encourages scientific investigation and exploration through observation, research and experiments implemented through individual, paired and group work.

"As students mature, they are expected to expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students are also expected to improve their abilities to interpret data by identifying significant features and patterns, use mathematics to represent relationships between variables, and take into account sources of error. When possible and feasible, students should use digital tools to analyze and interpret data. Whether analyzing data for the purpose of science or engineering, it is important students present data as evidence to support their conclusions." (NGSS, appendix F).

The MYP learning of science relies on "understanding and using the language of science" to communicate scientific information (IBO, 2011, p 15), thereby emphasizing the value of science learning beyond just learning the scientific terminology, also providing opportunities to assess the engineering design practices of the NGSS.

To solve engineering problems, engineers follow a series of steps called the "engineering design process" (Engineering is elementary, a curriculum provided by the Museum of Science, Boston).

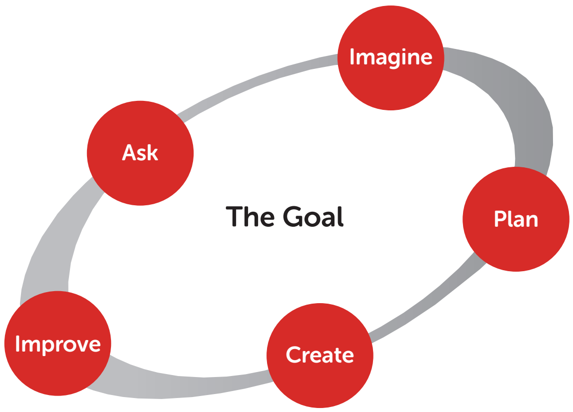

Figure 18: Engineering is Elementary, Museum of Science, Boston

ASK: What is the problem? How have others approached it? What are your constraints?

IMAGINE: What are some solutions? Brainstorm ideas. Choose the best one.

PLAN: Draw a diagram. Make lists of materials you will need.

CREATE: Follow your plan and create something. Test it out!

IMPROVE: What works? What doesn't? What could work better? Modify your design to make it better. Test it out!

The engineering design cycle as proposed by the NGSS juxtaposed with the MYP design cycle (see figure 13a) highlights clearly the high degree of congruence between the NGSS performance expectations and the MYP science aims and objectives. This is further substantiated through the philosophy of science learning across the IB continuum that promotes student engagement in scientific inquiry, collection of accurate information, analysing information, offering explanations and refining understanding.

It is impossible to evaluate the three dimensions of the NGSS through one-dimensional assessments. The MYP assessment criteria (IBO, 2015a, p 2) succinctly brings forth the possibility of assessing three-dimensional science learning through the following unique descriptors that teachers use to make judgments about students' work.

Criterion A: Knowing and understanding. Students develop scientific knowledge (facts, ideas, concepts, processes, laws, principles, models and theories) and apply it to solve problems and express scientifically supported judgments.

Criterion B: Inquiring and designing. Students develop intellectual and practical skills through designing, analysing and performing scientific investigations.

Criterion C: Processing and evaluating. Students collect, process and interpret qualitative and/or quantitative data, and explain conclusions that have been appropriately reached.

Criterion D: Reflecting on the impacts of science. Students evaluate the implications of scientific developments and their applications to a specific problem or issue. Varied scientific language is applied to demonstrate understanding. Students should become aware of the importance of documenting the work of others when communicating in science.

MYP students thus have immense opportunities to experience both continuous formative assessments (with appropriate and timely feedback to improve learning and inform planning) and summative assessments (at the end of their course). Schools realize this vision by embedding a variety of assessments such as projects, exhibitions, oral presentations, performances, demonstrations, written papers and essays. It is evident that each of these approaches offers immense possibilities to integrate and assess all three dimensions of the NGSS within the MYP in a meaningful and rigorous way.

The values and applications of morality, ethics, culture, politics, environment and sociology permeate the MYP sciences through meaningful and real-world exploration (IBO, 2015a). In this sense, and as already highlighted in this report, the MYP offers immense possibilities for incorporating the three dimensions of the NGSS through inquiry-based authentic learning projects.

The NRC also recommends the meaningful incorporation of computer-based technology within perform ance assessments:

"When appropriate, computer-based technology should be used to broaden and deepen the range of performances used on these assessments." (Recommendation 6–2)

In this area, the MYP eAssessments and ePortfolios seem to offer the required scope and potential to incorporate the philosophy of the NGSS to to offer more authentic and engaging scenarios by incorporating technology-based assessments. The following table (IBO, 2016, p 39) brings forth this alignment of philosophy and practice of the NGSS and the MYP.

Sciences examination blueprint

Overview

The following table illustrates how on-screen examinations in the sciences assessment are structured.

Task	Marks	Main criteria assessed	Criterion marks
Knowing and understanding	30	A	30
Investigation skills	60	B	30
		C	30
Applying science	30	D	30
	120		

Sources

A variety of sources feature in each assessment and could include the following.

- Data tables
- Static images
- Videos
- Animations
- Simulations
- Graphs

Figure 19: MYP sciences examination blueprint

Assessment in the DP and NGSS

While it can be argued that the science courses in the DP offer the scope and potential of realizing the complex and in-depth performance expectations as articulated by the NGSS, the DP also poses some significant pragmatic challenges in the dual implementation. The overarching issues in implementing the NGSS within the DP can broadly be identified as follows:

- Although the DP sciences have the potential to embed the three-dimensional approach required by the NGSS, perhaps this is currently not achieved consistently and coherently.
- With regards to the engineering component, although it is impossible to achieve the IB philosophy of learning by doing without embedding the EDP, this is perhaps not articulated as evidently as it should be to meet the requirements of the NGSS.
- There is very limited opportunity to explore the Earth and space sciences, although this is possible via the DP geography course.

In this context it becomes paramount to recognize the holistic nature of the DP, fostered particularly through the components of the extended essay (discussed earlier) and theory of knowledge (TOK). The overall aim of TOK, to encourage students to formulate answers to the question "how do you know?" in a variety of contexts, allows students to develop an enduring fascination with the richness of knowledge. The aims of the TOK course are to:

- make connections between a critical approach to the construction of knowledge, the academic disciplines and the wider world
- develop an awareness of how individuals and communities construct knowledge and how this is critically examined
- develop an interest in the diversity and richness of cultural perspectives and an awareness of personal and ideological assumptions
- reflect critically on their own beliefs and assumptions, leading to more thoughtful, responsible and purposeful lives
- understand that knowledge brings responsibility which leads to commitment and action. (IBO, 2014c)

Each of the above aims enables the realization of the NGSS performance indicators through many possibilities for scientific exploration, thereby questioning and developing scientific ways of knowing and reasoning based on evidence. Ideally, when a student opts for two or more sciences in the DP, the opportunity to demonstrate mastery over the NGSS performance expectations seems to be more realistic. Students who pursue more than one science course in the DP will have the opportunity to demonstrate mastery in the NGSS performance expectations in a more complex and in-depth manner. DP group 4 sciences include:

- biology
- computer science
- chemistry
- design technology
- physics
- sports, exercise and health science
- environmental systems and societies (SL only).

Students who have followed the MYP in the dual implementation model will have a great advantage of being better prepared for the depth and rigour of the DP and the NGSS.

The development of communication skills and the understanding of the language of sciences are fundamental for understanding and learning science; this fact is acknowledged by both MYP science and DP group 4 experimental sciences (IBO, 2011, p 32).

However, the course selection criteria available for DP students may result in some students taking only one science subject, and it is not only unrealistic but also against the vision of the NGSS that all of the performance indicators should be assessed within one science discipline. This will mean that much of the NGSS performance expectations need to be covered in grades 9 and 10 if **all** students need to demonstrate proficiency in these. Other pragmatic challenges include the fact that DP science teachers often teach only one of the IB courses and are often qualified only in one of the sciences. This poses some serious challenges in terms of teacher readiness and professional development in moving towards a more interdisciplinary approach as required by the NGSS.

The formal assessment of the DP includes, but is not limited to, multiple-choice tests (for a few subjects) and examination papers (for most subjects), and is intended to be taken at the end of the two-year course. A variety of other tasks (essays, research essays, written assignments, oral interviews, scientific and mathematical investigations, fieldwork projects and artistic performances) spread over different subjects and completed by students at various times under various conditions during their course offer much potential to incorporate the NGSS performance expectations within DP assessments. The notion of scientific inquiry guided by student curiosity and questioning, through an iterative refinement of practices is also recommended by the NRC:

"Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g. measuring specific properties of materials)—to those that emerge from students' own questions." (NRC, 2012, p 61)

A useful starting point would then be for teachers to map out connections between the IB assessment objectives and the NGSS performance expectations. (see figure 20)

IB assessment objectives	NGSS connections in a performance expectation
1. Demonstrate knowledge and understanding of: • Facts, concepts, and terminology • Methodologies and techniques • Communicating scientific information	
2. Apply: • Facts, concepts, and terminology • Methodologies and techniques • Methods of communicating scientific information	
3. Formulate, analyse, and evaluate: • Hypotheses, research questions, and predictions • Methodologies and techniques • Primary and secondary data • Scientific explanations	

Figure 20: Mapping IB assessment objectives and NGSS performance expectations

This assessment objective for DP sciences places a clear emphasis on critical questioning by requiring that students "formulate, analyse, and evaluate hypotheses, research questions, and predictions; analyse and evaluate methodologies and techniques, primary and secondary data, and scientific explanations". Additionally, the evidence and reasoning embedded within good scientific questions relates to other DP assessment objectives as a means for students to demonstrate their knowledge, understanding, and application of concepts and methodologies.

Developing and using models

"Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and imagine a world not yet seen. Models enable predictions of the , "if … then … therefore," to be made in order to test hypothetical explanations. Engineering makes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem. Engineers also call on models of various sorts to test proposed systems and to recognize the strengths and limitations of their designs." (NRC, 2012)

Models are a powerful tool for students to communicate their thinking about how and why phenomena occur. In high school, NGSS define modelling as going beyond representing a phenomenon or problem, and having explanatory or predictive value. The emphasis on modelling is conceptual, rather than physical; models can take many forms, including physical, mathematical, and conceptual.

While the development and use of models is not explicitly called for in DP science aims and objectives, some of the conceptual underpinnings of this practice (for example, communicating the connection of concepts and ideas to a phenomenon) are clearly inherent in the DP assessment objectives and group 4 aims. DP assessment objectives 1 and 2 ask that students demonstrate and apply their knowledge and understanding of ideas as well as methodology, including the communication of scientific information. Assessment objective 3 asks that students formulate predictions, hypotheses, and research questions, and evaluate data, explanations, and predictions, which are integral components of modelling as a science and engineering practice.

Moreover, as science and engineering are often concerned with using what is known or observed to construct viable explanations or arguments, modelling is directly related to some of the group 4 aims, such as "acquire, apply, and use a body of knowledge, methods, and techniques that characterize science and technology" and "develop an ability to analyse, evaluate, and synthesize scientific information".

Planning and carrying out investigations

"Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g. measuring specific properties of materials)—to those that emerge from students' own questions." (NRC, 2012, p 61)

Knowing how to turn a question into an investigation that can produce evidence to answer that question is fundamental to science and engineering. The NGSS stress student understanding and demonstration of both the "how" and "why" of investigations, asking students to consider the relationships between data, evidence, and the question at hand; the reliability, precision, and limitations of data resulting from an investigation; the relationship between investigations and the other science practices; and the ethical and social considerations of investigative work in science. This is central to all of the DP science courses, as suggested by the aims "develop experimental and investigative scientific skills, including the use of current technologies", and "become critically aware, as global citizens, of the ethical implications of using science and technology".

Additionally, several of the assessment objectives are directly related to this practice. Objectives 1, 2 and 3 all ask students to demonstrate, apply, and evaluate their knowledge and understanding of methodologies, techniques, and concepts (for example, evidence), which are paramount to proficient demonstration of this practice at the high school level.

Analysing and interpreting data

"As students mature, they are expected to expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students are also expected to improve their abilities to interpret data by identifying significant features and patterns, use mathematics to represent relationships between variables, and take into account sources of error. When possible and feasible, students should use digital tools to analyze and interpret data. Whether analyzing data for the purpose of science or engineering, it is important students present data as evidence to support their conclusions." (NGSS, 2012, appendix F)

Scientific understanding is predicated on the ability to organize data in ways that are supportive of finding relationships and patterns within the data, and interpreting those patterns in meaningful ways, grounded in scientific reasoning. In high school, the NGSS ask that students use appropriate tools and statistical methodologies to analyse the data, consider limitations of data analysis, compare various types of data sets for consistency, and evaluate the impact of new data on existing working explanations, arguments, and models. DP science courses specifically intend for students to "develop an ability to analyse, evaluate, and synthesize scientific information" and "develop experimental and investigative skills including the use of current technologies". Assessment objective 3 also asks that students be able to "analyse and evaluate primary and secondary data", in addition to the relationship analysing data might have to modifying or revising explanations, arguments, and models (also reflected in objective 3). Importantly, this practice has a direct relationship to mathematics, by emphasizing the role of statistical methods and mathematical concepts related to organizing and identifying patterns (for example, graphical displays, mathematical functions designed to fit data sets). This is one clear opportunity for students to "develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge" (a group 4 aim).

Using mathematics and computational thinking

"Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question." (NRC, 2012, p 65)

Using mathematics and computational thinking is closely linked to quantitative evidence, and specifically to the other SEPs "developing and using models" and "analysing and interpreting data". In high school, students "use algebraic thinking and analysis, and a range of linear and non-linear functions including trigonometric functions, exponentials, and logarithms, and computational tools to analyse, represent, and model data" (National Academies Press 2012: 42). Students are responsible for creating and using simple computational simulations of phenomena, and testing mathematical/computational models to see if a model "makes sense" based on what is known about the natural world, and use appropriate mathematical units, quantities, and conversions in complex measurement problems tied to the real world.

Like analysing and interpreting data, this practice is closely tied to DP aims and objectives relating to demonstrating and applying tools to analyse and evaluate information, as well as developing an understanding of the relationship between science and mathematics.

Constructing explanations and designing solutions

"Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur. In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science." (NRC, 2012, Pp 68–69)

Explanations (in science) and solutions (in engineering) are the goals of inquiry. In high school, the NGSS ask that students construct explanations and design solutions to problems that are "supported by multiple and independent student-generated sources of evidence, consistent with scientific ideas, principles, and theories" (NRC, 2012, appendix F). Students make claims about the relationships between variables, construct and revise explanations based on reliable evidence and knowledge of natural laws and theories, and evaluate how well evidence and reasoning supports a given explanation. In engineering, students design, evaluate, and refine solutions to complex real-world problems based on evidence, prioritized criteria, and trade-offs.

DP science courses emphasize students' ability to evaluate and synthesize scientific information (a group 4 aim) and apply and use a body of knowledge and methods that characterize science (a group 4 aim). Moreover, DP assessments in science include formulating, analysing, and evaluating scientific explanations (assessment objective 3).

Engaging in argument from evidence

"The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose." (NRC, 2012, p 73)

Critical evaluation and questioning of claims, evidence, and reasoning in a respectful way are paramount for success in science in global contexts. The NGSS asks that students use evidence and reasoning to make and defend claims and explanations, and respectfully critique, question, and evaluate those of their peers. Argumentation is inherently a vehicle for discourse in a variety of forms, and so supplies students with opportunities to develop scientific communication skills, in addition to deep critical thinking skills. In high school, students compare and evaluate competing arguments and design solutions, evaluate currently accepted explanations and solutions to determine the merits of the arguments, and respectfully probe reasoning and evidence to provide and receive critiques of proposed explanations and arguments.

Because argumentation involves both critical thinking about scientific information as well as effective communication in scientific and engineering contexts, there are several points of overlap with DP features. Argumentation is intimately related to the analysis and evaluation of data, evidence, and scientific explanations, as well as the application of concepts and communicating scientific information.

Obtaining, evaluating, and communicating information

"Being able to read, interpret, and produce scientific and technical text are fundamental practices of science and engineering, as is the ability to communicate clearly and persuasively. Being a critical consumer of information about science and engineering requires the ability to read or view reports of scientific or technological advances or applications (whether found in the press, the Internet, or in a town meeting) and to recognize the salient ideas, identify sources of error and methodological flaws, distinguish observations from inferences, arguments from explanations, and claims from evidence." (NRC, 2012, appendix F)

This practice focuses on evaluating and communicating acquired information, with an emphasis on critical evaluation of the validity and reliability of claims, methods, and designs in the information. Additionally, students are responsible for communicating scientific information in varied and appropriate ways, such as orally, graphically, mathematically, and in written forms. This is an important research skill set and a clear way for students to demonstrate and apply their understanding of the practice as well as scientific ideas, and this practice has a clear relationship to DP aims and assessment objectives relating to 21st century communication skills and the relationship between science and other disciplines.

Group 4 aims and assessment objectives

The DP group 4 project that focuses on scientific investigation also offers significant potential in terms of realizing some of the goals of the dual implementation. The group 4 project as an interdisciplinary activity requires students to draw on the knowledge, understanding and skills from a variety of disciplines in the DP. Hence, within the group 4 project, teachers can use the opportunity to strategically plan the integration of the three dimensions of the NGSS.

The group 4 aims are explicitly broader than the performance expectations of the NGSS, as they include global awareness, ethical implications, and cognitive reflection on the relationship between sciences and non-scientific disciplines. However, at their core, the group 4 aims are highly complementary to the expected outcomes of an NGSS-aligned programme of study. Both the DP and NGSS expect students to:

- develop knowledge and skills around a wide range of scientific concepts and approaches
- know how and when to apply those skills and knowledge to make sense of the world
- be critical, analytical, investigative, and evaluative when considering information
- collaborate and communicate effectively.

Group 4 aim	Examples of some possible relationships to the NGSS*
Appreciate scientific study and creativity within a global context through stimulating and challenging opportunities	Emphasis on real-world phenomena and problems; using three-dimensional learning to explain and solve
Acquire a body of knowledge, methods, and techniques that characterize science and technology	DCIs, SEPs, CCCs; three-dimensional performance expectations
Apply and use a body of knowledge, methods, and techniques that characterize science and technology	Three-dimensional learning and performance; integration of DCIs, CCCs, SEPs Performance expectation: HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

Group 4 aim	Examples of some possible relationships to the NGSS*
Develop an ability to analyse, evaluate, and synthesize scientific information	SEPs (specifically 4–8) Example from NGSS practice matrix: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. Example from NGSS CCC matrix: Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments.
Develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities	SEPs (specifically 7 and 8) Example from NGSS practice matrix: Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions.
Develop experimental and investigative scientific skills including the use of current technologies	SEPs (1–8) Example from NGSS practice matrix: Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g. number of trials, cost, risk, time), and refine the design accordingly. Example from CCC matrix: Models (e.g. physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.
Develop and apply 21st century communication skills in the study of science	SEPs Example from practice matrix: Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e. orally, graphically, textually, mathematically).
Become critically aware, as global citizens, of the ethical implications of using science and technology	ETS; CCCs; DCIs; SEP 3
Develop an appreciation of the possibilities and limitations of science and technology	SEPs, CCCs, DCIs
Develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge	CCCs; connections to CCSS; maybe SEP 4/8?

Figure 21: Possible relationships—group 4 aims and NGSS

* Note: these are only some examples of relationships that can be articulated between the NGSS and group 4 aims. This chart is not intended to be comprehensive or prescriptive, and educators should explore additional and alternative relationships in their own approach to instruction and assessment.

Laying emphasis on the process involved in scientific investigation rather than the finished product provides students with the opportunity to mirror the work of real scientists. Exploring the possibility of incorporating aspects of NGSS-related courses not traditionally covered by the DP (such as the earth sciences and physical sciences) within the group 4 project could also be useful.

However, the critical gap in the dual implementation seems to be the current unavailability of specific courses in the DP on engineering, and the Earth and space science components of the NGSS. While there is immense possibility to meaningfully integrate this within science courses currently available, this is more teacher-dependent rather than a course requirement, which can result in gaps and inconsistencies in the way this is interpreted and implemented. While some degree of mapping can be done for the disciplinary core ideas and DP sciences, the scientific and engineering practices and crosscutting concepts components of the performance expectations of the NGSS do not lend themselves to one-to-one comparisons with the current structure of the DP science courses.

Other DP courses like design technology, information technology in a global society and computer science also offer immense potential to map out some meaningful pathways to meet the NGSS performance expectations (although this is again a possibility that needs further exploration). Students not opting for sufficient science courses in the DP will be required to explore the scope of theory of knowledge and the extended essay to meet the required performance indicators. Teachers in the DP can work collaboratively with science teachers and DP coordinators to come up with a plan to guide students through this path.

IB World Schools will also benefit from consulting the *Accelerated NGSS Model Course Maps* document to consider alternative options for how students can complete the high school performance expectations through multiple scheduling options for five-, four- and two-year models. (An overview of the accelerated pathways is available in National Academies Press [2015]). Another useful and time-saving approach towards building a coherent path to implementing the three dimensions would be "bundling" which refers to the grouping of the NGSS performance expectations with respective evidence statements for the purposes of both instruction and assessment. However, there is no one optimal way to do this bundling, hence this once again calls for teacher collaboration, planning and professional development.

The range of assessment systems practised in different states also come with their own strengths and weaknesses, highlighting that there can be no one-size-fits-all formula in devising a universal best practice in designing assessments.

IB assessments incorporating the NGSS

Explicitly making connections between the disciplinary core ideas as recommended by the framework (such as using understandings about chemical interactions from physical science to explain biological phenomena [NRC, 2014, p 1]) needs considerable rethinking in light of IB assessments (across the continuum). If science education needs to integrate the scientific practices, the disciplinary core ideas and the crosscutting concepts through a coherent and "synergistic" (Erickson, 2008) approach in instruction and assessment, it cannot be achieved through "minor tinkering" (NRC, 2014).

As already discussed earlier, IB assessments have much potential to incorporate the NGSS performance expectations. Adapted from the NRC (2000), Brunsell et al. (2014, p 56) provide a list of questions that give teachers guidance on modifying classroom investigations and in evaluating a science inquiry to align more closely to the NGSS:

- Do students identify their own scientifically oriented questions or is a question given to them?
- Do students have an opportunity to determine what data should be collected and design methods to collect that data?

- Does the learning engagement encourage students to seek out additional information, connect to known science and/or share results with classmates?

- Does the learning engagement require students to make sense of data by generating an evidenced-based explanation to attempt to answer the questions?

- Does the scientific exploration provide an opportunity for students to engage in argumentation from evidence, justifying their explanations and/or critiquing the explanation of others?

The above questions offer some guidance on evaluating current assessments in the IB programmes to then consider how to embed the NGSS. The NRC (2014) committee also encourages that schools adopt a "bottom up" approach rather than a "top down" one:

"one that begins with the process of designing assessments for the classroom, perhaps integrated into instructional units, and moves toward assessments for monitoring. In designing these assessment materials, development teams need to include experts in science, science learning, assessment design, equity and diversity, and science teaching". (Recommendation 4–2)

The team of experts mentioned needs to work alongside experienced IB educators to construct meaningful assessments that reflect the breadth and the rigour of the IB and the NGSS. This will also require considerable investment in terms of time and planning (both short and long term):

"States will need to carefully lay out their priorities and adopt a thoughtful, reflective, and gradual process for making the transition to an assessment system that supports the vision of the framework and the NGSS. States should also build into their commissions adequate provision for the substantial amounts of time, effort, and refinement that are needed to develop and implement the use of such assessments; multiple cycles of design-based research will be necessary." (Recommendation 7–3)

Professional development

"What is of paramount importance in the pre-university stage is not what is learned but learning how to learn … What matters is not the absorption and regurgitation either of fact or pre-digested interpretations of facts, but the development of powers of the mind or ways of thinking which can be applied to new situations and new presentations of facts as they arise." (Peterson, 1972)

This quote by Alec Peterson sheds light on how the IB was conceived (almost 50 years ago) with the philosophy and principles of real-world, inquiry-based conceptual learning, all of which are the cornerstones of the NGSS. Reiterating this will establish the notion that the NGSS is not something totally new to the existing teaching and learning philosophy and practice in IB World Schools.

Hence, an ideal starting point for professional development in the NGSS would be to highlight the cornerstone of IB education, promoting an inquiry-based approach to facilitate deep-conceptual engagement through real-life scenarios, achieved through the student-centred approaches to teaching and learning as articulated by the IB.

Brunsell et al (2014) point out that professional development in the NGSS needs to particularly address two specific areas: the first, curricular decisions and the second, pedagogical development. Given that IB teachers are often well trained and comfortable in non-traditional classroom strategies this will be easier to implement in IB World Schools. However, there is not a button that can be pressed to make the transition for the dual implementation occur quickly. Also, one often-heard comment from teachers after a quick glance at the NGSS is: "we already do all of this". While the IB programmes resonate with many of the core elements of the NGSS, it is worth reflecting on whether or not science instruction consistently targets all three dimensions and whether or not the assessments reflect the breadth and rigour of each of the three dimensions. Professional development needs to be purposefully integrated into teacher training in a way that it not only supports teachers during this transition, but also makes the process more consistent and sustainable.

Teacher anxiety to some extent is understandable, but this can be reduced through strategic planning and administrative support. All stakeholders need to work cohesively towards building capacity in understanding and implementing the NGSS within the IB programmes. Needless to say, short-, medium- and long-term plans in bringing about capacity building and implementation need to be chalked out. Considerable time needs to be allowed for administrator and teacher orientation. In this sense, the most critical part of that support must come from administrators (McLaughlin and Marsh, 1978) since the energy, drive and enthusiasm needed to make the shot will depend on whether the administrators consider it important (Brunsell et al, 2014).

Modelling of lessons by administrators and co-teaching with teachers will be a very useful strategy.

"To lead learning means to model a 'learner-centered', as opposed to an 'authority-centered' approach to all problems, inside and outside the classroom." (Senge et al, 2000, Pp 416–417)

Professional development should foster activities that allow teachers to collaborate, share, and discuss implementing NGSS as a team. In a learner-centred environment, all people in the system are viewed as learners and act as learners.

Parents will also need to be educated on the pedagogical shifts that will be evident in student learning. Particularly since one goal of *A Framework for K–12 Science Education* and the NGSS is for there to be a move away from the "inch-deep, mile-wide" by identifying a smaller set of coherent ideas that students can explore in depth, most courses will need to be revised to reduce the number of topics that are covered each year. Parents will need to be educated about this "unburdening of the curriculum" so that the true vision of the NGSS can be realized.

While there are already a number of professional development resources available in print and online, an integral component in professional development workshops would be to help teachers understand the curriculum design principles that bind the core of the IB and the NGSS together. Explaining the structure of knowledge (Erickson, 2012) and the "synergistic" thinking facilitated through this structure in order to meet the factual and conceptual rigour of science learning so that what students know, understand and are able to do can be assessed through the NGSS performance expectations.

Another useful approach that professional development facilitators can adopt to help teachers make connections between the NGSS and the IB (particularly the PYP and MYP) would be to map out the commonalities between PYP and MYP key and related concepts to the NGSS crosscutting concepts and design assessments that best bring out this alignment. Some examples of this have been provided in this document.

It will be helpful for professional development facilitators to highlight the commonalities in the approaches of both the IB and the NGSS, but caution should be taken to ensure that this does not translate into a "tick the box" exercise. This approach also runs the risk of concepts being interpreted as topics, which is not the intention of either the IB or the NGSS. While the concepts as identified in the PYP and the MYP are "macro concepts" (that provide breadth and connections across and between disciplines), the NGSS crosscutting concepts are "micro concepts" in the sense that they give teachers and students the opportunity to explore the sciences in depth, while making it possible to make connections between the various science disciplines.

Both the IB and the NGSS place value on the professional expertise of teachers, with each teacher bringing their own experience, expertise, and perspective into the implementation. This will enable the implementation to be successful and enriching within its dimensions. It is not possible to enjoy, experience and reap the true benefits of three-dimensional learning through a one-dimensional "one-size-fits-all" approach.

It is also important to bear in mind that while professional development facilitators can work towards providing the necessary scaffolding and some effective pathways for engaging in the dual implementation, providing too many one-to-one mappings of the components of the IB and the NGSS should not disempower teachers from finding their own creative ways to explore the numerous pathways for bringing about the dual implementation effectively.

Needless to say, states will need to include adequate time and resources for professional development so that teachers can be properly prepared and guided and so that curriculum and assessment developers can adapt their work to the vision of the framework and the NGSS (NRC, 2014, Recommendation 7–2).

Conclusion

The NGSS framework challenges the traditional ways in which science has been taught in schools, with no evident opportunities for students to explore scientific phenomena by engaging in scientific practices. The NGSS provide the scaffolding needed to meaningfully facilitate this exploration by tailoring engineering, design and technology lessons that bring forth the synergy between scientific explorations and mathematical concepts. While highlighting the potential of the IB curriculum framework within each of the programmes (PYP, MYP and DP) to incorporate the NGSS with intellectual rigour and integrity, the study draws attention to the nuances of the challenges for each of the programmes in terms of this dual implementation in IB World Schools.

Through an inquiry-based approach to curriculum and instruction, the IB philosophy calls for teaching and learning to move beyond the regurgitation of factual content by empowering students to engage in deep conceptual understanding. Similarly, the NGSS strive to focus on a limited number of disciplinary core ideas and crosscutting concepts, so as to enrich the application of scientific practices and the understanding of core scientific ideas, designed in a way that students continually build on and revise their knowledge and abilities over multiple years.

It is also important to note that according to the NRC, the goals of the NGSS framework are meant for **all students** and not just for those who want to pursue careers in science, engineering, or technology. It is believed that all students will benefit from the learning experiences generated by student-directed scientific explorations and the thought processes involved in the engineering, design aspects of the NGSS. (Further guidance on planning for inclusion is available in appendix 4). The requirement of the DP for all students to take a science course and a mathematics course plus TOK aligns with the NGSS goals.

The NGSS emphasize the necessity of viewing engineering, design and technology in a broad sense compared to the narrow view that IB World Schools currently adopt. Incorporating the engineering, design and technology requirement within the PYP will involve a paradigm shift, moving from a structured inquiry methodology to a practice-based approach to inquiry.

If the engineering design practices are to be explored by PYP students by personally engaging in scientific inquiry in each of the disciplinary core ideas, there seem to be considerable challenges for PYP schools initially in terms of time, resources and assessment. This is not to say that it is impossible for schools to integrate meaningfully engineering, design and technology within the PYP, but rather to acknowledge the need for focused professional development for teachers. Schools also need to set aside quality time to understand and develop a sustainable plan towards realizing the vision of the NGSS.

The study highlights the potential of the MYP in being able to integrate the engineering design aspects more efficiently than the other two IB programmes (PYP and DP). The MYP design cycle complements the cycle of research and design that is at the centre of learning in a STEM-based approach to the study of engineering and design, and offers immense possibilities for incorporating the NGSS through inquiry-based, authentic learning projects to integrate engineering, design and technology.

Through the various options available in the DP (such as design technology, information technology in a global society and computer science) the potential for meaningful integration of the NGSS is both feasible and logical. However, the need for considerable shifts in terms of curriculum redesign through interdisciplinary approaches will need some significant attention. (An example of incorporating STEM and interdisciplinary teaching within the DP course information technology in a global society is available in appendix: 5).

Through a "synergistic" approach of factual and conceptual engagement, the DP geography course, because it is highly conceptual in nature, provides the opportunity to explore topics concerning poverty reduction, gender equality, improvements in health and education and environmental sustainability, thereby offering the opportunity to incorporate the Earth and space science component of the NGSS.

The study has also drawn attention to the need to redesign the paper-based DP assessments to successfully integrate the practice-based engineering, design and technology requirements of the NGSS. Working by the principle of "backwards by design", the ideal approach would then be to consider the NGSS as a vehicle for translating the IB curriculum framework into practice by keeping in mind the ultimate goals in terms of what the students should be able to "know, understand and do" (Erickson, 2008) at the end of each grade level.

It is pertinent to note that the purpose of the relationship study is not to engage in a "match making" exercise between the IB philosophy and the NGSS. While the IB is a curricular framework and the NGSS are performance expectations, teachers facilitating transition between the IB programmes engaged in the dual implementation will benefit from seeing the NGSS as moving schools one step closer (and a much-needed step) towards realizing the IB's vision through measurable outcomes.

It is also important to recognize the high level of flexibility the NGSS afford educators and students in terms of meeting the standards. Although some creativity in approach and restructuring of instruction or internal assessments may be necessary, the mutually supportive goals and intentions of the DP and the high school NGSS performance expectations suggest a promising road ahead, albeit not one devoid of challenges.

While highlighting the high degree of congruence between the IB and the NGSS, the relationship study report also provides some question prompts to stimulate dialogue and discussions to generate a deeper understanding of the sciences across the continuum in the IB.

From these questions, further questions have been generated in order to provide a springboard for teachers, administrators, curriculum developers and professional development facilitators who are engaged in the journey of the dual implementation. These questions include:

- In what ways does the teaching and learning of science in the IB programmes reflect the philosophy of the NGSS and vice versa?
- To what extent do the attributes of the IB learner profile and approaches to teaching and learning help strengthen the dual implementation of the IB and the NGSS?
- How does implementation of the NGSS within the IB programmes help build the progression of essential science concepts, knowledge and skills within and between each of the programmes?
- Is there an understanding of the non-negotiable aspects in terms of the nature and approach of the teaching and learning of science across the IB continuum when implementing the NGSS?
- What measures have schools taken to help teachers, students and parents understand the role and significance of adopting and implementing the NGSS?
- What measures has the school taken to dispel the myths and apprehensions in aligning to the NGSS?

- What does student inquiry look like in PYP, MYP and DP science inquiry when aligning to the NGSS?
- Is there an understanding of how the specific features within each of the IB programmes contribute to the three-dimensional teaching of science as recommended by the NGSS?
- How might the school ensure that scientific inquiry supports both the acquisition of language and the construction of meaning as recommended by the CCSS and the NGSS?

The effective implementation of the IB and the NGSS demands a "synergistic" interplay between science, technology, mathematics and the social sciences. In this sense it calls for a "systems thinking" approach (Fullan, 2005) within IB World Schools to implement this with intellectual integrity and rigour. This also highlights the need for considerable professional development that is "sustained, job-embedded, collegial, integrative, practical and results oriented" (Fogarty and Pete, 2010) in meeting this demand.

As highlighted at the beginning of this report, the overarching goal of both the IB and the NGSS is moving beyond the teaching and learning of science as a body of factual information to fostering scientific inquiry (aimed at deep conceptual engagement) and is an area of powerful synergy between the two. The NGSS only reinforce and strengthen the IB's philosophy and practice of curriculum and instruction ever since its inception in 1968. This can serve as a great starting point for teachers to begin unpacking and implementing them.

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Appendix 1: Matrix of crosscutting concepts and disciplinary core ideas in the NGSS

NGSS@NSTA
STEM STARTS HERE

Matrix of Crosscutting Concepts in NGSS

K-2	3-5	6-8	9-12
Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.			
• Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence	• Similarities and differences in patterns can be used to sort, classify, communicate and analyse simple rates of change for natural phenomena and designed products. • Patterns of change can be used to make predictions. • Patterns can be used as evidence to support an explanation.	• Macroscopic patterns are related to the nature of microscopic and atomic-level structure. • Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems. • Patterns can be used to identify cause and effect relationships. • Graphs, charts, and images can be used to identify patterns in data.	• Different patterns may be observed at each of the scales at which a system is studies and can provide evidence for causality in explanations of phenomena. • Classifications or explanations used at one scale may fail or need revision when informaiton from smaller or larger scales is introduced, thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analysed and • interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns • Empirical evidence is needed to identify patterns. •
Cause and Effect: Mechanism and Predictions: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.			
• Events have causes that generate observable patterns. • Simple tests can be designed to gather evidence to support or refute student ideas about causes.	• Cause and effect relationships are routinely identified, tested, and used to explain change. • Events that occur together with regularity might or might not be a cause and effect relationship.	• Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. • Cause and effect relationships may be used to predict phenomena in natural or designed systems. Phenomena may have more than one cause, and some • cause and effect relationships in systems can only be described using probability.	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cuase a desired effect. • Changes in systems may have various causes that may not have equal effects.
Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.			
• Relative scales allow objects and events to be compared and described (e.g., bigger and smaller, hotter and colder, faster and slower). • Standard units are used to measure length.	• Natural objects and/or observable phenomena eist from the very small to the immensely large or from the very short to the very long time periods. Standard units are used to • measure and describe physical quantities such as weight, time, temperature, and volume.	• Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or small. • The observed function of natural and designed systems may change with scale. • Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. • Scientific relationships can be represented through the use of algebraic expressions and equations. Phenomena that can be observed at one scale may not • be observable at another scale.	• The significance of a phoenomenon is dependent on the scale, proportion, and quantity at which it occurs. • Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. • Patterns observable at one scale may not be observable or exist at other scales. • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth.

Matrix Developed by NSTA 5/9/2013
http://nstahosted.org/pdfs/ngss/MatrixOfCrosscuttingConcepts.pdf

Disciplinary Core Ideas in the Next Generation Science Standards (NGSS) Final Release

Topic	Primary School (Grades K-2)	Elementary School (Grades 3-5)	Middle School (Grades 6-8)	High School (Grades 9-12)
Life Science				
LS1: From Molecules to Organisms: Structures and Processes				
LS1.A: Structure and Function	• All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water and air. Plants also have different parts (roots, stems, leaves, flowers, fruits) that help them survive and grow. (1-LS1-1)	• Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. (4-LS1-1)	• All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular). (MS-LS1-1) • Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. (secondary to MSLS3-2) • Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. (MS-LS1-2) • In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions. (MS-LS1-3)	• Systems of specialized cells within organisms help them perform the essential functions of life. (HS-LS1-1) • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (HS-LS1-1) (secondary to HS-LS3-1) • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (HS-LS1-3)
LS1.B: Growth and Development of Organisms	• Adult plants and animals can have young. In many kinds of animals, parents and the offspring themselves engage in behaviors that help the offspring to survive. (1-LS1-2)	• Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles. (3-LS1- 1)	• Animals engage in characteristic behaviors that increase the odds of reproduction. (MS-LS1-4) • Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction. (MS-LS1-4) • Genetic factors as well as local conditions affect the growth of the adult plant. (MS-LS1-5)	• In multicellular organisms individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. (HS-LS1-4)
LS1.C: Organization for Matter and Energy Flow in Organisms	• All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow. (K-LS1-1)	• Food provides animals with the materials they need for body repair and growth and the energy they need to maintain body warmth and for motion. (secondary to 5-PS3-1) • Plants acquire their material for growth chiefly from air and water. (5- LS1-1)	• Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. (MS-LS1-6) • Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. (MS-LS1-7)	• The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5) • The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6) • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7) • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another and release energy to the surrounding environment and to maintain body temperature. Cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. (HS-LS1-7)
LS1.D: Information Processing	• Animals have body parts that capture and convey different kinds of information needed for growth and survival. Animals respond to these inputs with behaviors that help them survive. Plants also respond to some external inputs. (1-LS1-1)	• Different sense receptors are specialized for particular kinds of information, which may be then processed by the animal's brain. Animals are able to use their perceptions and memories to guide their actions. (4-LS1-2)	• Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories. (MS-LS1-8)	

Matrix Developed by NSTA 5/9/2013
http://nstahosted.org/pdfs/ngss/20130509/matrixofdisciplinarycoreideasinngss-may2013.pdf

Appendix 2: Sample lesson idea—grade 3 invention convention, PYP

PYP and NGSS engineering design cycle

Ms Machacek and M. Spring are PYP teachers. Grade 3 invention convention is an annual project they have designed to provide students with the opportunity to draw upon thinking, creativity and engineering design within the PYP transdisciplinary theme of "Where we are in place and time". PYP key concepts identified for the project are form, function and causation.

For this project, students are required to identify a need or real-life problem that could be solved by designing a new invention or by modifying an already existing invention. Once students go through the iterative process of problem-solving, they arrive at a possible design of their "invention". Students then build and test their invention (engineering design cycle). The project also incorporates a literacy component as students communicate and publish their thinking to support their invention work (for example, posters, labelled diagrams, newspaper articles, technology pieces, iMovie, PowerPoint, and so on).

Students present their inventions at the convention, along with (student-written) newspaper articles featuring their inventions and descriptive posters. All efforts are presented to "patent officers" and the aim is to persuade the officers that their invention is worthy of being "patented".

As well as providing a platform to demonstrate many of the IB learner profile attributes (thinkers, inquirers, risk-takers and communicators) in action, it is a great opportunity for the students to bring together all of the transdisciplinary skills of the PYP (thinking, social, research, communication and self-management) along with the opportunity to go through the engineering design cycle as proposed by the NGSS.

The project brings together innovation, entrepreneurship, engineering design cycle and literacy all within the PYP framework, yet seamlessly aligned to the NGSS. Future modification for the projects could be to identify the NGSS performance indicators that relate to the project.

Appendix 3: Crosscutting concepts—student prompts

Patterns (some question stems)

1. What patterns did you observe?
2. What predictions are possible based on the pattern?
3. How do you describe the pattern?
4. How can you use this pattern in an explanation?
5. Is there a way to use mathematics to describe the pattern?

Cause and Effect (some question stems)

1. What caused ____ to happen?
2. How could we test your idea about the cause?
3. Could the effect have more than one cause?
4. What predictions are possible from the cause-effect relationship?
5. How have you used the cause-effect relationship in a scientific argument?
6. How could we design a system/model to produce the same effect?

Scale, Proportion & Quantity (some question stems)

1. How do these objects/events compare? (bigger/smaller...)
2. Where does this object/event fit on the size/time scale?
3. How does scale help us think about this ___ (idea)?
4. How does quantity help us think about this ___ (idea)?
5. How does proportion help us think about this ___ (idea)?
6. Is the phenomenon visible at other scales? Explain your thinking.

Systems & Systems Models (some question stems)

1. What are the parts of the system?
2. Describe how the parts of the system interact.
3. What are the interactions of this system?
4. How does the model represent the system?
5. What assumptions/approximations are built into your system model?

Energy & Matter (some question stems)

1. What smaller pieces can this be brokin into?
2. How might we take these pieces and make something bigger?
3. Describe the cycles of matter represented in this system.
4. How do energy changes show up in this system?
5. How do energy and matter interact in this system?

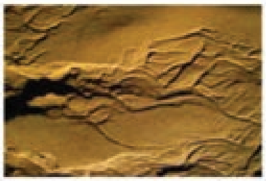
Structure and Function (some question stems)

1. Why is this ___ shaped like this?
2. What sub-structures are important in this ___ (object/system)?
3. How are the structures related to the functions found in this ___ (object/system)?
4. Design a different structure that might be able to perform the same function.
5. Desribe how the properties of the materials in this system are important.

Stability and Change (some question stems)

1. What stayed the same? What changed?
2. How does the system display stability?
3. What changes were occurring while the system was stable?
4. Descibe how the system is able to remain stable.
5. Where else have you seen this type of stability (or change)?
6. What role has feedback played in the stability/instability of the system?

Appendix 4: Crosscutting concepts—planning for inclusion

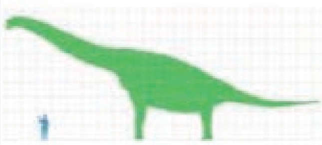


Patterns

Observed patterns of forms and events guide organization & classification, and they prompt questions about relationships and the factors that influence them.

Cause & Effect

Events have causes, sometimes simple, sometimes multifacteted. A major activity of science is investigating and explaining cuasal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

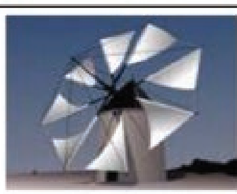


Scale, Proportion and Quantity

In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion or quantity affect a system's sturcture or performance.

Systems and Systems Models

Defining the system under study - speciftying its boundaries and making explicit a model of that system - provides tools for understnading and testing ideas that are applicable throughout science and engineering.

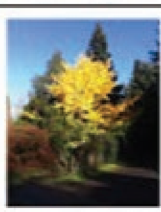


Energy and Matter

Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibliities and limitations.

Structure and Function

The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.



Stability and Change

For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Appendix 5: Sample lesson idea—DP STEM integration in robotics

Engineering design cycle through an interdisciplinary approach

Ms Sherifa teaches DP information technology in a global society (ITGS). She designed the robotics component of the ITGS HL course with the specific aim of integrating control engineering (mechanical, electrical, electronics), computer science and technology with maths and science. Her goal was to encourage students to engage in a STEM-integrated learning experience, and to encourage her students to become engineers like herself.

In the robotics course, students explore diverse techniques and make effective use of an appropriate range of basic and complex skills to create solutions for authentic situations. The level of complexity ranges from simple LEGO Mindstorm kits to more complex systems such as TETRIX. Students work in teams to brainstorm, build robotic systems, and troubleshoot different designs, thereby going through the iterative process of the engineering design cycle of the NGSS.

Throughout the course, while students acquire the knowledge and skills required to become the computer engineers and the programmers of the future, they also learn how to engage their critical thinking skills in order to consider their roles and responsibilities as digital citizens, hence, they make informed decisions and judgments about the effects of technology development on individuals and societies.

In addition, the course introduces students to computer programming and provides them with an understanding of the basic concepts of computer science. She also sees this is as an excellent opportunity for students to develop their coding skills and to be equipped with the knowledge required for the IB computer science course. She gives below a quick snapshot of how the integration is made possible:

Science:

Students develop the ability to identify specific phenomena in a system or factors that affect system performance by doing the following:

- Applying the basic concepts of scientific experiment: Observation, hypothesis, prediction, experimentation, and conclusion
- Dealing with qualitative data
- Experimenting with concepts such as force, motion and speed

Mathematics:

Students apply the basic concepts of mathematical equations in a more meaningful context. For example:

- Calculating distance travelled based on the number of rotations of an axle and the diameter of a wheel attached to the axle
- Calculating the speed and the acceleration
- Breaking down problems into smaller sections which lead to the basic concepts of programming

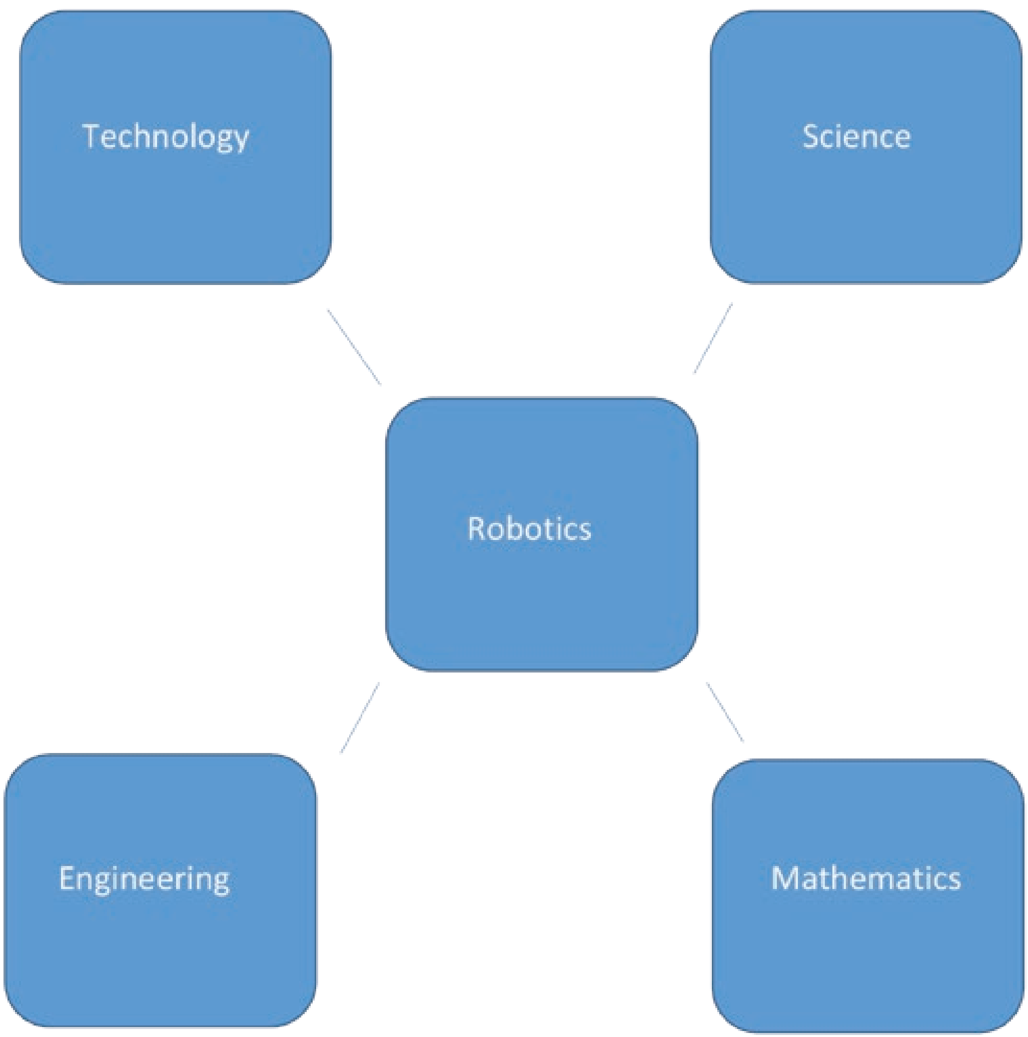
Technology:

Students develop a better understanding of the meaning of input, process and output, multisensory.

- With the use of different types of sensors, students learn how to apply their understanding of closed loop systems.
- A number of apps are now available to enable students to remotely control the robot using bluetooth technology.
- In addition, students learn to demonstrate their awareness of the social and ethical implications of the misuse of advanced technologies such as artificial intelligence to control such systems.

Engineering:

It is essential that students follow the engineering design cycle when they work on their projects within their groups. The stages—ask, imagine, plan, create and improve—are well documented by the students and are part of the assessment. Students document the stages in a digital portfolio with different artefacts that showcase the progress in the project. This provides evidence of authenticity and a basis for feedback and reflection.



Appendix 6: Teacher resources

Next Generation Science Standards (NGSS) website: http://www.nextgenscience.org/

Illinois State Board of Education's (ISBE) NGSS in Illinois website: http://www.isbe.net/ngss/default.htm

National Science Teachers Association (NSTA) NGSS website pages : http://www.nsta.org/about/standardsupdate/default.aspx, http://www.nsta.org/about/standardsupdate/standards.aspx

Achieve Inc: http://www.achieve.org/next-generation-science-standards

National Academies Framework Committee: http://sites.nationalacademies.org/DBASSE/BOTA/CurrentProjects/DBASSE_071506

Framework document: http://www.nap.edu/catalog.php?record_id=13165, http://www.ngss.info/?q=presenters

NGSS frequently asked questions: http://www.nextgenscience.org/frequently-asked-questions#1.1

Full Option Science System (FOSS). (nd). Retrieved from the Lawrence Hall of Science FOSS Website: http://www.lhsfoss.org/

Fusion curriculum: http://www.hmhco.com/shop/education-curriculum/science/elementary-science/sciencefusion

Interactive science: http://www.teachtci.com/science/interactive-science-textbooks-and-curriculum.html

Minnesota Mathematics and Science Teacher Partnership. (nd). Retrieved from the Region 11 Math and Science Teacher Partnership website: http://www.region11mathandscience.org/

National Academy of Engineering. 2009. *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC. The National Academies Press.

National Research Council. 1996. *National science education standards*. Washington, DC. The National Academies Press.

Peterson, ADC. 1987. S*chools across Frontiers: The Story of the International Baccalaureate and the United World Colleges*. La Salle, IL. Open Court.

Project Lead The Way (PLW): https://www.pltw.org/alignment

Partnership for Assessment of Readiness for College And Careers: http://www.parcconline.org

Smarter Balanced Assessment Consortium: Available at http://www.smarterbalanced.org/practice-test/

UTeach Engineering Program. (nd). Retrieved from the UTeach Engineering website: http://www.uteachengineering.org/

http://www.intellen.com/collections/enrichment-classes

Appendix 7: MYP teacher resources for curriculum planning

Teacher(s)		Subject group and discipline	Design (Product, digital and combined)		
Unit title	Zero Impact	Session		Unit duration (hrs) approximately	30

Inquiry: Establishing the purpose of the unit

Key concept	Related concept(s)	Global context
MYP: Communities **Communities** are groups that exist in proximity defined by space, time or relationship. Communities include, for example, groups of people sharing particular characteristics, beliefs or values as well as groups of **interdependent** organisms living together in a specific habitat. NGSS Crosscutting concepts: Stability and Change **Small changes** in one part of a system might cause large changes in another part.	MYP: Sustainability Resources NGSS Disciplinary Core Ideas:	Globalisation & Sustainability Aligns closely to NGSS Nature of Science: "Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes."
Statement of inquiry		
Communities consider sustainable resources available when designing environmentally friendly homes.		

Inquiry questions
Factual - What is meant by sustainability? What are the requirements for building an environmentally sound house? What roles do humans play in the ecosystem? **Conceptual** - How do we improve environmental aspects in house building when cost becomes a factor? Can human impact be minimised? **Debatable** - Is it important for us to consider the environmental impact of consumerism? Can humans have zero impact on the environment/ecosystem?

Objectives	Summative assessment	
All strands in all objectives: A - Investigating and Inquiring B - Developing Ideas C - Creating the solution D - Evaluation	**Outline of summative assessment task(s) including assessment criteria:** **MYP Design Cycle:** Students will use the Design cycle to compare and contrast the effective use of environmentally friendly building materials and products. They will investigate the need for sustainability and explore the concepts of change and progress for improvement. Students will find out how to calculate a carbon footprint and the importance of it. Students will use this research to help them formulate design ideas, which will culminate in one final design being created as a 3D model using software of their choice. A successful final product requires a 3D walkthrough for the client to visualise and understand how the final design works. As this is a year 5 project - all stages of the design cycle will be assessed as a whole.	Relationship between summative assessment task(s) and statement of inquiry: **MYP Design Cycle:** **Criterion A** - students will **explain** and **justify** possible problems, identify clients, **identify** and **prioritise** pertinent research and **analyse** and **develop** this information to appreciate the perspective of community needs for a final solution. **Criterion B** - students will **develop** specifications based on prior research into perspectives which will inspire and **develop a range** of design ideas, incrementally improved to **present** a final solution which is **justified fully and critically** against the specification. The final solution **accurately details** and **outlines** the requirements for creation.

Design sample planner

	Next Generation Science Standards: Connections to Engineering, Technology and Applications of Science Influence of Science, Engineering and Technology on Society and the Natural World. The use of technologies and any limitations on their use are driven by individual or societal needs, desires and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. The summative assessment allows students to explore these connections between design, technology and science and enables them to make informed decisions regarding the use of resources for sustainability. **Common Core State Standards: aligned to stages of Design Cycle** <u>A: "Investigating and Inquiring" stage:</u> ELA/Literacy: RST.6-8.8: Distinguish among facts, reasoned judgment based on research findings and speculation in a text	**Criterion C** - students will **construct a detailed and logical** plan. Appropriate technical skills are **demonstrated** and progression and improvements to the design and plan are evident and **justified**. The final design should consider the perspective of the community identified in criterion A. **Criterion D** - student will create **detailed, relevant and authentic** tests which will **evaluate** its success against the design specification. The evaluation should **explain** improvements to the solution and how they impact the identified community. **NGSS alignment:** <u>Assessable Component:</u> MS-LS2-5 Evaluate competing design solutions for maintaining biodiversity and ecosystem services. Clarification statement: examples of ecosystem services could include water purification, nutrient recycling, prevention of soil erosion, impact on finite resources through mining or removal. Examples of design constraints could include social, economic, scientific and cultural restraints. This should be linked back to the Global Context. <u>Scientific and Engineering Practices:</u>
	RI.8.8 Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and whether the evidence is relevant and sufficient to support the claims <u>B: "Developing ideas":</u> ELA/Literacy: RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection and research <u>C: "Creating the solution":</u> Mathematics: MP.2: Reason abstractly and quantitatively ELA/Literacy: RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g. in a flowchart, diagram, model, graph, or table). D: "Evaluation"/ Final product: ELA/Literacy: SL.8.5: Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence and add interest.	MS-LS2-2 Constructing explanations and designing solutions. Construct an explanation that includes qualitative or quantitative relationships between variable that predict phenomena MS-LS2-5 Engaging in Argument from Evidence Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MYP Design cycle to be used) HS-LS2-1 Using Mathematics and Computational Thinking Use mathematical and/or computational representations of phenomena or design solutions to support explanations. <u>NGSS Crosscutting Concepts:</u>

Design sample planner

Approaches to learning (ATL)
Thinking - Critical thinking skills - Analyse a range of existing products that inspire a solution to the problem **Research** - Information Literacy - Develop a detailed design brief which summarizes the analysis of relevant research **Communication** - Communication skills - Fully justify changes made to the chosen design and plan when making the solution **Self management** - Reflection skills - Plan the creation of the chosen design / solution **Thinking** - Critical Thinking - Critically evaluate the success of the solution against the design specification **Self Management** - Organisation skills - Design detailed and relevant testing methods, which generate data, to measure the success of the solution Additional SEPs from NGSS could also be aligned to ATLs

ACTION: Teaching and learning through inquiry

Content	Learning process
MYP: Calculation of carbon footprint based on Household Energies: Equations for household energy category courtesy of the EPA Household Greenhouse Gas Calculator for Electricity, Natural Gas,Fuel Oil, Propane, Wood Burners etc. Environmentally conscious building techniques - Recycled Steel, Plant-based Polyurethane Rigid Foam, Insulation from straw bales, Recycled Wood/Plastic Composite Lumber, Low-E Windows, Vacuum Insulation Panels are amongst many other techniques and ideas. Renewable energies such as wind and water turbines, vegetable fuels, solar power, heat exchange pumps, cooling systems etc. Possible areas of instruction throughout the course of the unit could include looking research skills for the research section; correct use of the MLA formatted referencing. The use of formulae within Excel and the creation of GANTT charts to visually represent this data. **NGSS:** **Disciplinary Core Ideas:** LS2.C Ecosystem Dynamics, Functioning and Resilience	**Learning experiences and teaching strategies** Depending on how the unit is delivered it may be classified as Digital Design, Product Design or even as a combined digital and design project. Students may be open to creating a digital final product or a more tangible solution such as a card, balsa wood or other such material culminating in a scale model of their chosen design. **Formative assessment** Since this is a Year 5 project the formative assessments will be as usual however for recording and reporting purposes these will be limited to verbal classwork and feedback. **Differentiation** All students will have access to the Year 5 assessment criteria that will help them better understand the levels achievable for themselves.

Design sample planner

LS4.D Biodiversity and Humans ETS1.B Developing Possible Solutions There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem	Provided with a glossary for key terms and concepts to ensure EAL students can access Adaptive technologies for students with physical needs - taking into account other impairments - visual aids such as printing documents on various colours, font sizes.

Resources
Students will have access to all prior projects, units that have been completed and the school VLE (Virtual Learning Environment). Students will have access to all software currently installed on the school servers / network and have the prior knowledge to use them. IBMYP 5 criteria and task specific clarifications will be given to students. Access to printed materials - access to library & multi-media resources.

REFLECTION: Considering the planning, process and impact of the inquiry

Prior to teaching the unit	During teaching	After teaching the unit
Through prior teaching and learning students will have investigated and used various types of software and techniques which will allow them to access the higher grade boundaries. Students will have worked through the MYP1-4 years and should have acquired a good knowledge base and understanding of MYP assessment criteria. Students will be introduced to MYP criteria. . Informally collaborate with Maths and Science teachers to investigate possible interdisciplinary links. Opportunities for meaningful service learning may arise through student's research into effective recycling techniques. Multilingualism may be incorporated by opportunities to identify with their unique vocabulary and context from their various languages and cultures. Teachers should be familiar with the NGSS documentation, particularly Appendix K to ensure their design remains aligned with the ETS standards	Students will be given guidance to follow prior units from MYP4 and their knowledge base in order to create a project, which will allow them to access the higher grade boundaries. Guidance will be limited to the allowed amount prescribed by the IB and teachers will be present to act as a facilitator to the students. Good Health and safety techniques for the safety of students are paramount.	Review of the unit will be beneficial to the teachers and students alike. Perhaps a questionnaire or some sort of survey monkey may be best advised to ensure confidentiality for survey takers.

Design sample planner

Teacher(s)		Subject group and discipline	Sciences (chemistry) **NGSS MS-PS1** MS-PS1-2 MS-PS1-3 MS-PS1-4		
Unit title	Energy and chemical change	MYP year	3	Unit duration (hrs)	25

Inquiry: Establishing the purpose of the unit

Key concept	Related concept(s)	Global context
MYP Change: change is a conversion, transformation or movement from one form, state, or value to another. Inquiry into the concept of change involves understanding and evaluating causes, processes, and consequences. NGSS Crosscutting concept: **Cause and Effect**: Students classify relationships as causal or correlational, and recognize that correlation does not necessarily imply causation. They use cause and effect relationships to predict phenomena in natural or designed systems. They also understand that phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	**MYP: Interaction, consequences, energy** Related NGSS Crosscutting concepts: • **System and System Models** • **Cause and Effect** • **Matter and Energy** NGSS Disciplinary Core Ideas: **Matter and its interactions**: This core idea helps students to formulate an answer to the question, "How do atomic and molecular interactions explain the properties of matter that we see and feel?" by building understanding of what occurs at the atomic and molecular scale.	**Scientific and technical innovation: Ingenuity and Progress** NGSS Relationships: Similar to the NGSS concept **Influence of Engineering, Technology, and Science on Society and the Natural World.**

Statement of inquiry		
Change created by interaction(s) can have positive consequences that lead to ingenuity and progress Chemical reactions can be used to create new substances with distinct properties from the original substances. This process can be leveraged to create and/or identify novel uses for substances that were previously inappropriate for an intended purpose. Changes caused by interactions between two or more substances can create new substances with properties that have positive consequences (effects) when applied within a system with a specific goal or problem, leading to ingenuity and progress within that system.		
Inquiry questions		
Factual: What consequences come from interactions? **Conceptual:** Why is the interaction occurring? **Debatable:** Is it possible to have change without consequences or progress?		
MYP Objectives	**Summative assessment**	**Relationship between summative assessment task(s) and statement of inquiry**
MYP Objective B: Investigating i. describe a problem or question to be tested by a scientific investigation ii. outline a testable hypothesis and explain it using scientific reasoning iii. describe how to manipulate the variables, and describe how data will be collected iv. design scientific investigations. Related NGSS Practices: Asking Questions and Defining Problems: • Ask questions that can be investigated	Building toward the following NGSS Performance Expectations: **MS-PS1-2** Analyze and interpret data on the properties of substances before and after the substances interact to determine if a reaction has occurred **MS-PS1-3** Gather and make sense of information to describe that synthetic materials come from natural resources and impact society	**Criterion B:** Students will be able to describe a problem regarding temperature changes in two different types of chemical reaction (endothermic and exothermic). Students will be given specific reactions/reagents to be tested during the investigation. They will be able to outline and explain a testable hypothesis based on the analysis of different variables, such as volume, surface area and amount of substance. The design must include how to manipulate these variables and

within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles. Planning and Carrying out Investigations: • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. **MYP Objective C: Processing & Evaluating** i. present collected and transformed data ii. interpret data and describe results using scientific reasoning iii. discuss the validity of a hypothesis based on the outcome of the scientific investigation iv. discuss the validity of the method v. describe improvements or extensions to the method. <u>Related NGSS Practices</u> Planning and Carrying Out Investigations: • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that	**MS-PS1-4** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. **Science and Engineering Practices:** See practice elements indicated under MYP objectives **Crosscutting Concepts:** **Patterns** Macroscopic patterns are related to microscopic and atomic-level structure. **Cause and Effect** Cause and effect relationships may be used to predict phenomena in natural or designed systems. **Structure and Function** Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped used. **Disciplinary Core Ideas:** PS1.A: Structure and Properties of Matter • Each pure substance has characteristic physical and	how sufficient data will be collected. A logical, complete and safe method is expected. **Criterion D:**: Students will explore different types of chemical reactions and how these reactions have helped in the development of new technology within the automobile industry. Students will have the opportunity to explore how engineers design new products to solve the problem of improving a car's performance. Students must describe and analyse the implications of science in solving the problem through exploring its impact on society, and the effect on the environment, using written or oral skills. Students are required to acknowledge the work of others and the sources of information used by appropriately documenting them (in written or verbal form) using a recognized referencing system. **NGSS:** Students understand two components of the core ideas, including: the structure and properties of matter, and chemical reactions. By the end of this unit, students will be able to apply understanding that pure substances have characteristic physical and chemical properties and are made from a single type of atom or molecule. They will be able to provide

meet the goals of the investigation. • Evaluate the accuracy of various methods for collecting data. Analyzing and Interpreting Data: • Analyze and interpret data to provide evidence for phenomena. • Distinguish between causal and correlational relationships in data. • Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials). Obtaining, Evaluating, and Communicating Information: • Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations. **MYP Criterion D: Reflecting on Impacts** i. describe the ways in which science is applied and used to address a specific problem or issue ii. discuss and analyse the various implications of the use of science and its application in solving a specific problem or issue iii. apply scientific language effectively iv. document the work of others and sources of information used. **Note**: reflection in science is similar to the knowledge component of the practices in the	chemical properties (for any bulk quantity under given conditions) that can be used to identify it. • Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. • In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. • The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. **<u>Investigation:</u>** Students design an investigation into temperature changes in endothermic and exothermic reactions. Students use evidence from the investigation, along with scientific knowledge, to develop a model to describe the mechanisms underlying endothermic vs. exothermic reactions. **Goal** - (SOI) Change created by interaction(s) can have positive	molecular level accounts to explain states of matters and changes between states, that chemical reactions involve regrouping of atoms to form new substances, and that atoms rearrange during chemical reactions. Students are also able to apply an understanding of the design and the process of optimization in engineering to chemical reaction systems.

NGSS, and are related to all practices listed previously.	consequences that lead to ingenuity and progress Assessment task: "You have been tasked with writing an article for the company's blog explaining how all natural materials are actually used to make your company's synthetic ones, and describe the impact on society."	

Approaches to learning (ATL)
In order to describe a problem or question to be tested by a scientific investigation….students will…practice observing carefully in order to recognize problems (Category: Thinking, Cluster: Critical Thinking) In order to ii. outline a testable hypothesis and explain it using scientific reasoning….students will…make guesses, ask "what if" questions and generate testable hypotheses (Category: Thinking, Cluster: Creative Thinking) In order to describe how to manipulate the variables, and describe how data will be collected, students will organize and depict information logically (Category: Communication, cluster: Communication)

Action: Teaching and learning through inquiry

Learning process			
Content	**Learning experiences & teaching strategies**	**Formative assessment**	**Differentiation**
NGSS Disciplinary Core Ideas: • PS1.A: Structure and Properties of Matter. • PS1.B: Chemical Reactions • PS3.A: Definitions of Energy **NGSS Science and Engineering Practices:** • Asking Questions and Defining Problems • Analysing and Interpreting Data • Developing and Using Models • Planning and Carrying Out Investigations • Constructing Explanations and Designing Solutions • Engaging in Argument from evidence • Obtaining, Evaluating, and Communicating Information **NGSS Crosscutting Concepts:** • Systems and system models • Patterns • Energy and Matter • Cause and Effect	Student-driven learning experiences, with carefully planned teacher facilitation (questioning, pushing student thinking without providing answers) Creation of opportunities for students to access the materials, by creating their own personal learning goals or identifying interests within the scope of the learning goals for the unit. Students learn the conceptual and factual information through direct engagement with the SEPs, CCCs, and DCIs in a three dimensional way (as opposed to a lecture format, followed by confirmatory hands-on experiences). Socratic Seminar on information found for their article as well as the outcomes of experiments.	Student performances across the practices will serve throughout the unit as formative assessment opportunities. one-on-one conversations with students sharing out of ideas within small groups development and revision of models, experimental plans, and other communications	Sentence Frames with varying levels of support; Use Newsela for different lexile levels Provide more structured investigations for those that need additional support. Disciplinary vocabulary in the footer of student task sheets for reference. Adjust pairings/ groups as needed to provide language and collaborative support. Provide opportunities for student thinking to be demonstrated in diverse ways (e.g., oral communication, diagrams, storyboards, concept maps, written approaches)

MYP unit planner

Teacher(s)		Subject group and discipline	Sciences (chemistry)		
Unit title	Energy and chemical change	MYP year	3	Unit duration (hours)	15

Inquiry: Establishing the purpose of the unit

Key concept	Related concept(s)	Global context
Change	Interaction Consequences	Scientific and technical innovation: the impact of scientific and technological advances on communities and environments

Statement of inquiry

A change in matter is a consequence of energy differences between substances which scientists and technicians use to create a range of innovative products

Inquiry questions

Factual

- How can it be known that mass is conserved?

Debatable

- How is a glow stick like a firefly?

Conceptual

- How do observations indicate a substance change?
- How have chemical reactions impacted upon the automobile industry?

Objectives:	Summative assessment	
B: all strands D: all strands	**Outline of summative assessment task(s)** Investigation B: all strands B: design an investigation into temperature changes in endothermic and exothermic reactions. Reflection D: all strands D: reflect on the impact of the use of chemical reactions in the automobile industry.	**Relationship between summative assessment task(s) and statement of inquiry** • B: Students will be able to describe a problem regarding temperature changes in two different types of chemical reaction (endothermic and exothermic). Students will be given specific reactions/reagents to be tested during the investigation. They will be able to outline and explain a testable hypothesis based on the analysis of different variables, such as volume, surface area and amount of substance. The design must include how to manipulate these variables and how sufficient data will be collected. A logical, complete and safe method is expected. • D: Students will explore different types of chemical reactions and how these reactions have helped in the development of new technology within the automobile industry. Students will have the opportunity to explore how engineers design new products to solve the problem of improving a car's performance. Students must describe and analyse the implications of science in solving the problem through exploring its impact on society, and the effect on the environment, using written or oral skills. Students are required to acknowledge the work of others and the sources of information used by appropriately documenting them (in written or verbal form) using a recognized referencing system.

Approaches to learning (ATL)
Thinking: critical thinking—gather and organize relevant information to formulate an argument.
Self-management: reflection—consider ethical, cultural and environmental implications.
Thinking: creative thinking—use brainstorming and visual diagrams to generate new ideas and inquiries.
Communication: communication—give and receive meaningful feedback.
Communication: communication—use appropriate forms of writing for different purposes and audiences.
Communication: communication—take effective notes in class.
Communication: communication—structure information in summaries, essays and reports.
Communication: communication—reference, cite accurately, create footnotes and construct a bibliography according to recognized conventions.
Self-management: organization—select and use technology effectively and productively.
Research: information literacy—collect, record and verify data.
Research: information literacy—evaluate and select information sources and digital tools based on their appropriateness to specific tasks.
Research: media literacy—communicate information and ideas effectively to multiple audiences using a variety of media and formats.

Action: Teaching and learning through inquiry

Content	Learning process
• The law of the conservation of mass • Physical change, chemical change, reactant, product, combustion • Definition of the terms "catalyst" and "precipitate" • Writing word and symbol equations • Importance of the subscript (and coefficient) in equations • The changes in matter in terms of physical changes and chemical changes and the types of evidence that identify a chemical change from a physical change and how this is related to energy change • Types of chemical reactions: single-/double-displacement reaction,	**Learning experiences and teaching strategies** It would be nice if at least a demonstration could be included to show the law of conservation of mass. Students will be given general information about chemical reactions in real life, use and knowledge of key terms, physical and chemical changes and how to balance chemical equations. Perhaps include an activity to compare and contrast a chemical change with a physical one. (For example, dissolving copper sulphate in water (physical) then adding Zn to create the reaction—the temperature could be monitored to show the difference.) Students will be divided into small groups and will conduct laboratory experiments to

decomposition, synthesis, combustion reaction, endothermic and exothermic • Identifying the names and formulas for common laboratory acids and alkalis • Balancing chemical equations (Limited to simple compounds and elements or counting atoms/number of particles in a diagrammatic problem) • Chemistry in the automobile industry: common chemical reactions (for example, catalytic converters) • Concept that chemical potential energy is stored within compounds and that it can be released in a controlled manner to do work or produce heat	record evidence of chemical reactions. During these experiments, students will be able to observe, predict, record and conclude, based on the results. Students will visit an automobile manufacturing plant to observe different processes and to obtain specific information about devices previously mentioned/online simulations (optional). Another similar fieldtrip could be planned depending on local industry availability. Search: *I didn't know that: Air bags* (published by National Geographic). 22 May 2012. www.youtube.com Present relevant information to a specific audience (classmates, teachers, parents, etc) using different means of communication.
	Formative assessment Students will be given different worksheets to test their understanding on physical and chemical changes, balancing chemical equations and describing and analysing important chemical reactions in real life. Students will perform laboratory investigations to collect, organize and present data. What are some signs that a chemical reaction has taken place? Use of a data table to record observations and predictions to compare main characteristics of each sample. Then students will design an extension to the method or analyse another possible reaction for experimenting with. Students will design a format to register information during the visit to the manufacturing automobile plant and this information will be written as a summary and shared with their peers to receive feedback about the most important issues/aspects of the task (application of science, addressing the specific problem and the analysis of the advantages and disadvantages of the application).
	Differentiation **Different ways of delivering information** Opportunities to participate in different activities during the unit. 1. Basic information delivered to the student using media resources 2. Use of the ICT resources room for simulations and information related to the topic 3. Visit to a manufacturing plant to observe specific processes and receive

	information on how specific devices work 4. ESL students could take photographs of a demonstration or experiment showing the steps and stages of each process. They can then create a cartoon first in their own language and then translate this into the language of instruction. 5. Students with learning support requirements students could be helped in building equations if they are given a set of cards with all the symbols and formulas on them. **Assessment** Different devices to be investigated according to the student's preference. • Catalytic converters • Semiconductors • Airbags Two different options to present the information 1. Written task: 500–1000 words 2. Oral/multi-media task: 3–6 minutes

Resources

- Class working environment with resources: internet access/multimedia resources (10 hours)
- Laboratory working environment with different materials/reagents and resources, and internet access/multimedia resources. Group working: 2–3 students per group; collaborative work at all times (6 hours)
- Visit to an automobile manufacturing plant: collaborative work/free online simulation (2–3 students per group) (2–4 hours)

Reflection: Considering the planning, process and impact of the inquiry

Prior to teaching the unit	During teaching	After teaching the unit

Appendix 8: DP teacher resources for curriculum planning

	IB	NGSS		
Topic 1 Cell Biology		PEs	secondary	DCIs
1.1	• According to the cell theory, living organisms are composed of cells.	MS-LS1-1	MS-LS1-1	MS.LS1.a
	• Organisms consisting of only one cell carry out all functions of life in that cell.	MS-LS1-1	MS-LS1-1	MS.LS1.a
	• Surface area to volume ratio is important in the limitation of cell size.	N/A	N/A	N/A
	• Multicellular organisms have properties that emerge from the interaction of their cellular components.	MS-LS1-3	HS-LS1-2	MS.LS1.a HS.LS1.a
	• Specialized tissues can develop by cell differentiation in multicellular organisms.	MS-LS1-3	HS-LS1-2	MS.LS1.a HS.LS1.a
	• Differentiation involves the expression of some genes and not others in a cell's genome.	HS-LS1-1	HS-LS1-1	HS.LS1.a
	• The capacity of stem cells to divide and differentiate along different pathways is necessary in embryonic development and also makes stem cells suitable for therapeutic uses.	N/A	N/A	N/A
1.2	• Prokaryotes have a simple cell structure without compartmentalization.	N/A	N/A	N/A
	• Eukaryotes have a compartmentalized cell structure.	N/A	N/A	N/A
	• Electron microscopes have a much higher resolution than light microscopes.	N/A	N/A	N/A
1.3				

Topic	1: Cell Biology	2: Molecular Biology	3: Genetics	4. Ecology	5. Evolution and biodiversity	6. Human physiology	DO NOT FIT
	HS-LS1-2	HS-LS1-1	HS-LS3-1	HS-LS2-3	HS-LS4-1	HS-LS1-3	HS-LS2-6
	HS-LS1-4	HS-LS1-6	HS-LS3-2	HS-LS2-4	HS-LS4-2	HS-LS1-2	HS-LS2-1
		HS-LS1-5	HS-LS3-3	HS-LS2-5	HS-LS4-3		HS-LS2-2
		HS-LS1-7	HS-LS1-1	HS-LS2-7	HS-LS4-4		HS-LS4-6
			HS-ETS1-1*	HS-LS1-5	HS-LS4-5		
			HS-ETS1-3*	HS-LS1-7	HS-ESS2-7		
				HS-ESS2-6	HS-ETS1-1*		
				HS-ESS3-4	HS-ETS1-3*		
				HS-ESS3-5	HS-ETS1-4*		
				HS-ETS1-1*			
				HS-ETS1-3*			
				HS-ETS1-4*			

Options	C. Ecology and Conservation
	HS-LS2-1
	HS-LS2-2
	HS-LS4-6

Topic	1: Stoichiometric relationships	2: Atomic structure	3: Periodicity	4. Chemical bonding and structure	5. Energetics/ thermochemistry	6. Chemical kinetics	7. Equilibrium	8. Acids and bases	9. Redox processes	10. Organic chemistry	11. Measurement and data processing	DO NOT FIT
	HS-PS1-7	HS-PS1-2	HS-PS1-1	HS-PS1-3	HS-PS1-4	HS-PS1-5	HS-PS1-6			HS-LS1-6		HS-PS2-3
	HS-PS3-1					HS-PS3-1	HS-ETS1-3*					HS-PS2-6
												HS-PS3-3
												HS-PS4-2
	15. Energetics/ Thermochemistry (AHL)											
	HS-PS3-4											
Options	A. Materials	D. Medicinal Chemistry										
	HS-PS2-6	HS-ETS1-1*										
	HS-PS4-2	HS-ETS1-2*										
		HS-ETS1-3*										

Topic	1: Measurements and Uncertainties	2: Mechanics	3: Thermal Physics	4. Waves	5. Electiricty and magnetism	6. Circular Motion and Gravitation	7. Atomic, Nuclear, and Particle Physics	8. Energy Production	DO NOT FIT
		HS-PS2-1	HS-PS3-4	HS-PS4-1	HS-PS2-5	HS-PS2-4	HS-PS1-8	HS-PS3-1	
		HS-PS2-2	HS-PS3-2		HS-PS3-5	HS-ESS1-4		HS-PS3-2	HS-PS2-6
		HS-PS2-3			HS-PS3-3			HS-PS3-3	
		HS-ETS1-2*			HS-ETS1-1*			HS-ETS1-1*	HS-PS4-2
		HS-ETS1-1*							
		11. Electromagnetic Induction (AHL)	12. Quantum and nuclear physics						
		HS-PS4-3	HS-PS4-4						
		HS-PS4-5							
Options:	D- Astrophysics								
	HS-ESS1-1								
	HS-ESS1-2								
	HS-ESS1-3								

Topic	1: Systems and models	2: The ecosystem	3: Human population, carrying capacity and resource use	4. Conservation and biodiversity	5. Pollution management	6. The issue of global warming	7. Environmental value systems	DO NOT FIT
		HS-ESS2-4	HS-LS2-1	HS-LS2-2	HS-ESS3-6	HS-ESS2-2	HS-LS2-7	
		HS-ESS2-6	HS-LS2-7	HS-ESS3-3	HS-ETS1-2*	HS-ESS3-5	HS-LS4-6	
		HS-ESS2-7	HS-ESS2-6	HS-ETS1-1		HS-ESS3-6	HS-ESS3-4	
			HS-ESS3-1	HS-ETS1-3		HS-ETS1-1*	HS-ESS3-2	
			HS-ESS3-2			HS-ETS1-3*	HS-ESS3-6	
						HS-ETS1-4*	HS-ETS1-3*	

Topic	1:Anatomy	2: Exercise physiology	3: Energy Systems	4. Movement analysis	5. Skill in sport	6. Measurement and evaluation of human performance	DO NOT FIT
	HS-LS1-2	HS-LS1-2	HS-LS1-6	HS-LS1-7	HS-LS3-1*	HS-LS1-3	
		HS-LS2-3*	HS-LS1-7				
			HS-LS1-2		* the focus would have to be on the genetic advantage of inherited traits that lead to an advantage in sport		
			HS-LS1-3				

Topic	1: Human factors and ergonomics	2: Resource management and sustainable production	3: Modelling	4. Final production	5. Innovation and design	6. Classic design	DO NOT FIT
		HS-ESS3-1	HS-ETS1-4	HS-PS2-6	HS-ETS1-1	HS-ETS1-1	
		HS-ESS3-2	HS-PS2-1*	HS-PS2-3*	HS-ETS1-3	HS-ETS1-2	
		HS-ESS3-3			HS-PS2-3*	HS-ETS1-3	
		HS-LS2-7			HS-PS2-1*	HS-PS2-1*	
		HS-ETS1-1					

NGSS/IB Alignment

NGSS Performance Expectation	Where it is likely to be covered in IB DP Curriculum
HS-PS1 Matter and its Interactions	
HS-PS1-1: Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms	Chemistry (Periodicity)
HS-PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.	Chemistry (Atomic Structure)
HS-PS1-3: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.	Chemistry (Chemical Bonding and Structure)
HS-PS1-4: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends on the changes in total bond energy.	Chemistry (Energetics/Thermochemistry)
HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.	Chemistry (Chemical Kinetics)
HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. ***expects integration of engineering component***	Chemistry (Equilibrium)
HS-PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	Chemistry (Stoichiometric Relationships)
HS-PS1-8: Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the process of fission, fusion, and radioactive decay.	Physics (Atomic, Nuclear, and Particle Physics)

HS-PS2 Motion and Stability: Forces and Interactions	
HS-PS2-1: Analyse the data to support the claim that Newton's Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	Physics (Mechanics) Design Technology (Modelling, Innovation and Design, Classic Design)
HS-PS2-2: Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	Physics (Mechanics)
HS-PS2-3: Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. ***expects integration of engineering component***	Physics (Mechanics) Design Technology (Final Production, Innovation and Design)
HS-PS2-4: Use mathematical rpresentatons of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Physics (Circular Motion and Gravitation)
HS-PS2-5: Plan and conduct an investigation to provide evidence that an electrical current can produce a magnetic field and that a changing magnetic field can produce an electrical current.	Physics (Electricity and Magnetism)
HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. ***expects integration of engineering component***	Design Technology (Final Production)
HS-PS3 Energy	
HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.	Chemistry (Stoichiometric Relationships, Chemical Kinetics, Energy Production)
HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).	Physics (Thermal Physics, Energy Production)
HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. ***expects integration of engineering component***	Physics (Electricity and Magnetism, Energy Production)
HS-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of defferent temperature are combined within a closed system results in a more uniform energy distribution among the components in the system.	Physics (Thermal Physics)
HS-PS3-5: Develop and use a model of two objects interacting through electrical or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Physics (Electricity and Magnetism)
HS-PS4 Waves and Their Applications in Technologies for Information Transfer	
HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves travelling in various media.	Physics (Thermal Physics)
HS-PS4-2: Evaluate questions about the advantages of using digital transmission and storage of information.	Computer Science (System Fundamentals)
HS-PS4-3: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.	Computer Science (Networks)
HS-PS4-4: Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.	
HS-PS4-5: Communicate technical information about how some technological devices use the principles of wave behaviour and wave interactions with matter to transmit and capture information and energy. ***expects integration of engineering component***	Computer Science (System Fundamentals, Networks)

HS-LS1 From Molecules to Organisms: Structures and Processes	
HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.	Biology (Molecular Biology, Genetics)
HS-LS1-2: Develop and use a model to illustrate the hierachical organization of interacting systems that provide specific functions within multicellular organisms.	Biology (Cell Biology, Human Physiology) Sports, Exercise & Health Science (Anatomy, Exercise Physiology, Energy Systems)
HS-LS1-3: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.	Biology (Human Physiology) Sports, Exercise & Health Science (Energy Systems, Measurement and Evaluation of Human Performance)
HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.	Biology (Cell Biology)
HS-LS1-5: Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	Biology (Molecular Biology, Ecology)
HS-LS1-6: Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.	Biology (Molecular Biology) Chemistry (Organic Chemistry) Sports, Exercise & Health Science (Energy Systems)
HS-LS1-7: Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.	Biology (Molecular Biology, Ecology) Sports, Exercise & Health Science (Energy Systems, Movement Analysis)
HS-LS2 Ecosystems: Interactions, Energy, and Dynamics	
HS-LS2-1: Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.	Environmental Systems & Societies (Human Population, carrying capacity and resource use)
HS-LS2-2: Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.	Environmental Systems & Societies (Conservation and Biodiversity)
HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.	Biology (Ecology) Sports, Exercise & Health Science (Exercise Physiology)
HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.	Biology (Ecology)
HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.	Biology (Ecology)
HS-LS2-6: Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.	
HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. ***expects integration of engineering component***	Biology (Ecology) Environmental systems & Societies (Human Population, Carrying Capacity, and Resource Use, Environmental Value Systems) Design Technology (Resource Management and Sustainability)
HS-LS2-8: Evaluate evidence for the role of group behaviour on individual and species' chances to survive and reproduce.	
HS-LS3 Heredity: Inheritance and Variation of Traits	
HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.	Biology (Genetics) Sports, Exercise & Health Science (Skill in Sport)
HS-LS3-2: Make and defend a claim based on evidence that inheritable genetic variations may result from 1) new genetic combinations through meiosis, 2) viable errors occurring during replication, and/or 3) mutations caused by environmental factors.	Biology (Genetics)
HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.	Biology (Genetics)

HS-LS4 Biologcial Evolution: Unity and Diversity	
HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.	Biology (Evolution and Biodiversity)
HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: 1) the potential for a species to increase in number, 2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, 3) competition for limited resources, and 4) the proliferation of those organisms that are better able to survive and reproduce in the environment.	Biology (Evolution and Biodiversity)
HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.	Biology (Evolution and Biodiversity)
HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.	Biology (Evolution and Biodiversity)
HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in 1) increases in the number of individuals of some species, 2) the emergence of new species over time, and 3) the extinction of other species.	Biology (Evolution and Biodiversity)
HS-LS4-6: Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.	Environmental Systems & Societies (Environmental Value Systems)
HS-ESS1 Earth's Place in the Universe	
HS-ESS1-1: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.	
HS-ESS1-2: Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.	
HS-ESS1-3: Communicate scientific ideas about the way stars, over their life cycle, produce elements.	

HS-ESS1-4: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.	
HS-ESS1-5: Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.	
HS-ESS1-6: Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.	
HS-ESS2 Earth's Systems	
HS-ESS2-1: Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.	
HS-ESS2-2: Analyse geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.	Environmental Systems & Societies (The Issue of Global Warming)
HS-ESS2-3: Develop a model based on evidence of Earth's interior to describe the cyclng of matter by thermal convection.	
HS-ESS2-4: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.	Environmental Systems & Societies (The Ecosystem)
HS-ESS2-5: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.	
HS-ESS2-6: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.	Biology (Ecology) Environmental Systems & Societies (The Ecosystem, Human Population, Carrying Capacity and Resource Use)
HS-ESS2-7: Construct an argument based on evidence about the simultaneous co-evolution of Earth's systems and life on Earth.	Biology (Evolution and Biodiversity) Environmental Systems & Societies (The Ecosystem)

HS-ESS3 Earth and Human Activity	
HS-ESS3-1: Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.	Environmental Systems & Societies (Human Population, carrying capacity and resource use) Design Technology (Resource Management and Sustainability)
HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios. ***expects integration of engineering component***	Environmental Systems & Societies (Human Population, carrying capacity and resource use, Environmental Value Systems) Design Technology (Resource Management and Sustainability)
HS-ESS3-3: Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity.	Environmental Systems & Societies (Conservation and Biodiversity) Design Technology (Resource Management and Sustainability)
HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. ***expects integration of engineering component***	Biology (Ecology) Physics (Circular Motion and Gravitation) Environmental Systems & Societies (Environmental Value Systems)
HS-ESS3-5: Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems.	Biology (Ecology) Environmental Systems & Societies (The Issue of Global Warming)
HS-ESS3-6: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.	Environmental Systems & Societies (Pollution Management, The Issue of Global Warming, Environmental Value Systems)
HS-ETS1 Engineering Design	
HS-ETS1-1: Analyse a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.	Biology (Genetics, Ecology, Evolution and Biodiversity) Physics (Mechanics, Electricity and Magnetism, Energy Production) Environmental Systems & Societies (Conservation and Biodiversity, The Issue of Global Warming) Computer Science (Computational Thinking, Problem Solving, and Programming) Design Technology (Resource Management and Sustainability, Innovation and Design, Classic Design)
HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	Physics (Mechanics) Environmental Systems & Societies (Pollution Management) Computer Science (Computational Thinking, Problem Solving, and Programming) Design Technology (Classic Design)
HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	Biology (Genetics, Ecology, Evolution and Biodiversity) Chemistry (Equilibrium) Environmental Systems & Societies (Conservation and Biodiversity, The Issue of Global Warming, Environmental Value Systems) Computer Science (Computational Thinking, Problem Solving, and Programming) Design Technology (Innovation and Design, Classic Design)
HS-ETS1-4: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problems.	Biology (Ecology, Evolution and Biodiversity) Environmental Systems & Societies (The Issue of Global Warming) Design Technology (Modelling)


IB PRIMARY YEARS PROGRAMME
SHARING THE PLANET
WHO WE ARE
WHERE WE ARE IN PLACE AND TIME
HOW WE EXPRESS OURSELVES
HOW THE WORLD WORKS
HOW WE ORGANIZE OURSELVES
LANGUAGE
SOCIAL STUDIES
MATHEMATICS
ARTS
SCIENCE
PHYSICAL, SOCIAL AND PERSONAL EDUCATION
ACTION
EXHIBITION
APPROACHES TO TEACHING
ATTITUDES
APPROACHES TO LEARNING
CONCEPTS
THE IB LEARNER PROFILE
INTERNATIONAL-MINDEDNESS


IB MIDDLE YEARS PROGRAMME
LANGUAGE AND LITERATURE
INDIVIDUALS AND SOCIETIES
MATHEMATICS
DESIGN
ARTS
SCIENCES
PHYSICAL AND HEALTH EDUCATION
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APPROACHES TO LEARNING
CONCEPTS
THE IB LEARNER PROFILE
INTERNATIONAL-MINDEDNESS


IB DIPLOMA PROGRAMME
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LANGUAGE ACQUISITION
INDIVIDUALS AND SOCIETIES
SCIENCES
MATHEMATICS
THE ARTS
THEORY OF KNOWLEDGE
EXTENDED ESSAY
CREATIVITY, ACTIVITY, SERVICE
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APPROACHES TO LEARNING
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INTERNATIONAL–MINDEDNESS

THE IB LEARNER PROFILE®

IB learner profile

The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

As IB learners we strive to be:

INQUIRERS
We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

KNOWLEDGEABLE
We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

THINKERS
We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

COMMUNICATORS
We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

PRINCIPLED
We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

OPEN-MINDED
We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

CARING
We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

RISK-TAKERS
We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

BALANCED
We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

REFLECTIVE
We thoughtfully consider the world and our ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.

IB CONTINUUM

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