# PLAYING WITH PROTONS GOES DIGITAL

## CONCEPTUAL AND METHODOLOGICAL FRAMEWORK

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| Abstract | This document presents an integrated conceptual and methodological framework for the Playing with Protons Goes Digital project and introduces the context and a comprehensive, yet easily digestible, exposition of rationale and the chosen methodologies and ideas. It aims at producing a unique approach that resonates with teaching and learning needs, considering the issues and gaps in knowledge and skills that have emerged in the context of the current pandemic.<br>In a sense, it attempts to answer and provide justification to the question "why Playing with Protons Goes Digital in education". It outlines and presents Playing with Protons Goes Digital vision and operational strategy towards the Deeper Learning in STEAM classroom, It develops a comprehensive rationale for the project in light of the state of the art in the field, current literature, curriculum specifications in the countries involved, contemporary practices in education, and the wider context when addressing creativity and innovative STEAM approaches in the classrooms through collaboration, communities of inquiry and the necessary digital tools and skills to be addressed. |
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# EXECUTIVE SUMMARY

**Playing With Protons Goes Digital** project is based on the development of a conceptual and methodological framework that builds on the essential features of creative Science Education that can facilitate Deeper Learning in STEM combined with Arts. The Playing With Protons Goes Digital framework supports creativity as a generic element in the processual and communicative aspects of the pedagogy by integrating arts (virtual arts, performing arts, design, music). Based on project-based and inquiry approaches teachers will be asked to create their own AR and VR projects to introduce their students in a variety of abstract and invisible concepts of microcosmos. The approach Is based on the Deeper Learning Competence Framework that will be used to capture learners' progress and understanding during such creative activities and populate their Deeper Learning profiles. The proposed framework will guide teachers during the project interventions towards better realizing their emerging role as coaches of learning and will provide the reference for the development of the assessment approaches and the enabling technologies that the project will develop. This document (O1) is the reference document in the project. It defines the essential features of creative science education and describes the proposed conceptual and methodological framework which is based on the specific features. Based on this work O2 and O3 will deliver a) a set of innovative scenarios that will guide teachers during the project implementation and b) a set of recommendations and guidelines for the design of the Playing With Protons Goes Digital AR Platform.

This document includes five main chapters:

**Chapter 1** describes the Playing With Protons Goes Digital Deeper Learning Paradigm and summarizes the main challenges to introduce the project in school settings across Europe and the characteristics of teaching for Deeper Learning in order to make sure that the participating schools and Educators are fully realizing the different aspects and conditions of the proposed intervention.

**Chapter 2** defines in practical terms for the educators the evidences of Deeper Learning in their classrooms. To do that we describe the Learners Deeper Learning Profiles by defining the partial abilities of the key deeper learning competencies in the form of educational objectives and outcomes.

**Chapter 3** aims to provide an idea of what deeper learning classrooms look like. We are describing the characteristics of the environment that can facilitate the development of the key deeper learning competences. The transformation of the classroom environment is important, but the development of innovative curricula is crucial in the proposed reform effort. The Big Ideas of Science are presented as the main reference framework for a seamless integration of science subjects, a key step for the adoption of a STEAM approach in the school practice.

**Chapter 4** moves towards the integration of the Arts as an enhancer of learning and describes more specifically how this emerged organically during the implementation of Playing With Protons Goes Digital. Arts will act as the backbone for the construction of student's artifacts and projects. Arts enhanced with technology are the perfect trigger for creativity and critical thinking, eventually leading to a far deeper learning experience for students and teachers.

**Chapter 5** concludes the document and provides the references to the upcoming project outputs. Annex 2 could act as an initial template for the design of the Playing With Protons Goes Digital activities providing the necessary guidance to the school communities, to the technical team who will develop the necessary tools for creation of the learners' projects and the research team who will have a reference for the assessment of the deeper learning competencies that the learners are expected to develop during their involvement in the Playing With Protons Goes Digital activities.

# 1

# PLAYING WITH PROTONS GOES DIGITAL AND THE DEEPER LEARNING PARADIGM

# 1 PLAYING WITH PROTONS GOES DIGITAL AND THE DEEPER LEARNING PARADIGM

## 1.1 WHAT IS DEEPER LEARNING?

Deeper learning is usually associated with the concept that the learners must achieve excellence at school through an equitable educational system. According to the National Research Council Committee (NRC, 2012; p. 5) deeper learning can be defined as:

> *"The process through which a person becomes capable of taking what was learned in one situation and applying it to new situations- in other words, learning for transfer... by developing cognitive, interpersonal and intrapersonal competencies"*

In this process learners acquire proficiency in a subject beyond just memorising facts and concepts, techniques or procedures. Learners understand the key principles and realise when, how they can apply what they have learned in new real situations. Thus, asks for more than mastering academic knowledge and grasping relevant skills. In their recent research study, the American Institutes for Research (AIR, 2015) define deeper learning as:

> *Deeper learning refers to the combination of a deeper understanding of core academic content, the ability to apply that understanding to novel problems and situations, and the development of a range of competencies, including people skills and self-management."*

The concept of deeper learning has been used both to describe a **set of competencies** or **educational objectives** and to **characterize a way of learning** (or a process) that promotes these competencies. The William and Flora Hewlett Foundation has defined deeper learning as (William and Flora Hewlett Foundation, 2013, p. 1):

- *Mastery of core academic content*
- *Critical thinking and complex problem-solving skills*
- *Collaboration skills*
- *Effective communication skills*
- *An understanding of how to learn*
- *Development of academic mindsets*

As a process, deeper learning is in alignment with the Partnership 21st Century Skills Framework, namely the 4C's (P21, 2010): Critical thinking and problem solving, Creative thinking and innovation, Collaboration, and Communication. The more skilled the learners become in learning how to apply these skills the more able they become in understanding deeper the academic content. As an outcome deeper learning results from the self-directed transfer of the 4C's to the student's understanding of a concept's meaning (Bellanka, 2015). Despite these different views all disciplinary standards documents that have been introduced since 2010 (Achieve, 2013; NGA & CCSSO, 2010a; NGA & CCSSO, 2010b) have a common reference point: deeper learning and the development of the 21st century skills do not happen separately from the understanding of knowledge in an academic discipline (mastery of academic content).

As we prepare learners for success in school today we are aware they will face a vastly different future. Our world changes rapidly and in a way that is different than what we have experienced in the past. Thus, the education system must be modified to serve the new generation of learners and prepare them for success in the 21st century.

Many reports (Carnevale Smith, and Strohl, 2013) show that a very small percent of future jobs will be available to high school graduates and dropouts and those jobs will be limited to mainly three low paying job classifications (sales and office support, blue-collar jobs, food and personal services). Moreover, the need of continuing education beyond the secondary level is highlighted in a report by the U.S. Center on Education and the Workforce report (Carnevale, Smith, and Strohl, 2010). Within the report it is stated that high school graduates (and dropouts) will be largely left behind in the future economy. Moreover, postsecondary education and training is not –as it used to be- the preferable path to middle and upper-level pathway but "*it is increasingly the only pathway*".

Despite the fact that deeper learning is referenced as an approach to help all learners master academic content and have access to higher education, it is found (ACT, 2006) that it also prepares high-school graduates to perform well in workforce training programs associated with "*jobs that are likely to offer both a wage sufficient to support a small family and the potential for career advancement*" (p. 8).

Deeper learning supports the delivery of rich core content to learners in innovative ways that allow them to learn and then apply what they have learned. Rigorous core content is the heart of the learning process; true deeper learning is developing competencies that enable graduating high school learners to be college and career ready and then make maximum use of their knowledge in life and work. Evidence also confirms that deeper learning environments positively influence not only student academic outcomes and but also student social-emotional factors (AIR, 2014).

## 1.2 EVIDENCE OF DEEPER LEARNING OUTCOMES

As it was discussed before deeper learning is a process where learners acquire proficiency in a subject beyond just memorising facts and concepts, techniques or procedures. Sutherland, Shin, and Krajcik (2010) state: "It is not enough for learners only to understand big ideas; in fact, they cannot develop integrated understandings of even these core ideas unless they use their knowledge in meaningful ways, applying what they know to a variety of contexts and to novel situations" (p. 4). Furthermore, researchers in the field argue that exposure to deeper learning teaching prepares learners to be successful thinkers, and citizens in their adult lives (Finegold & Notabartolo, 2010). They also argue that supporting learners to acquire both academic content knowledge and skills required to critically apply this knowledge facilitates the development of "competencies that enable graduating high school learners to be college and career ready and then make maximum use of their knowledge in life and work" (Alliance for Excellent Education, 2010, p. 1).

Emerging research suggests that exposure to deeper learning teaching correlates with increased academic achievement, leading to a more flexible and competent relationship with knowledge. Researchers at the Educational Policy Improvement Center (Collins et al., 2013) examined the impacts of a curriculum intended to promote deeper learning—the Road trip Nation Experience (RTN)—and found increases in the grade point average (GPA) of RTN learners compared to their peers. However, all of these studies note limitations or lack methodological documentation. Although early evaluation studies of schools participating in networks focused on deeper learning suggested positive effects, the studies had several limitations relating to their research designs, samples, data, measures, and/or analyses (Yuan & Le, 2010). More recent evaluations (Collins et al., 2013; Guha et al., 2014; Nichols-Barrer & Haimson, 2013) have also suggested positive program effects on indicators such as grade point average (GPA), progress to graduation, and state test results, but these studies are primarily descriptive in nature or have focused on demonstrating the effectiveness of specific instructional programs or approaches aligned with the goals of deeper learning.

Indeed, a recent NRC panel noted the limitations of existing research in creating links between deeper learning competencies and long-term student educational outcomes and recommended that foundations and federal agencies support further research in this arena (NRC, 2012). As a result of this limited empirical base, there has recently been increased interest in research that evaluates whether school approaches explicitly focused on developing deeper learning competencies are associated with improved educational opportunities for all learners.

The *Study of Deeper Learning: Opportunities and Outcomes* Report (AIR, 2014)—aimed to determine whether learners attending high schools with a mature approach to promoting *deeper learning* experienced greater deeper learning opportunities and outcomes than they would have had they not attended these schools.

For analysis and interpretation, the researchers grouped these competencies into three overlapping domains, as defined by the National Research Council (2012): the *cognitive domain*, including mastery of academic content knowledge and complex problem solving; *the interpersonal domain*, including collaboration and communication skills; and the *intrapersonal domain*, including an understanding of how to learn and academic mindsets such as motivation to learn, academic engagement, and self-efficacy (Farrington et al., 2012; Soland, Hamilton, & Stecher, 2013; NRC, 2012).

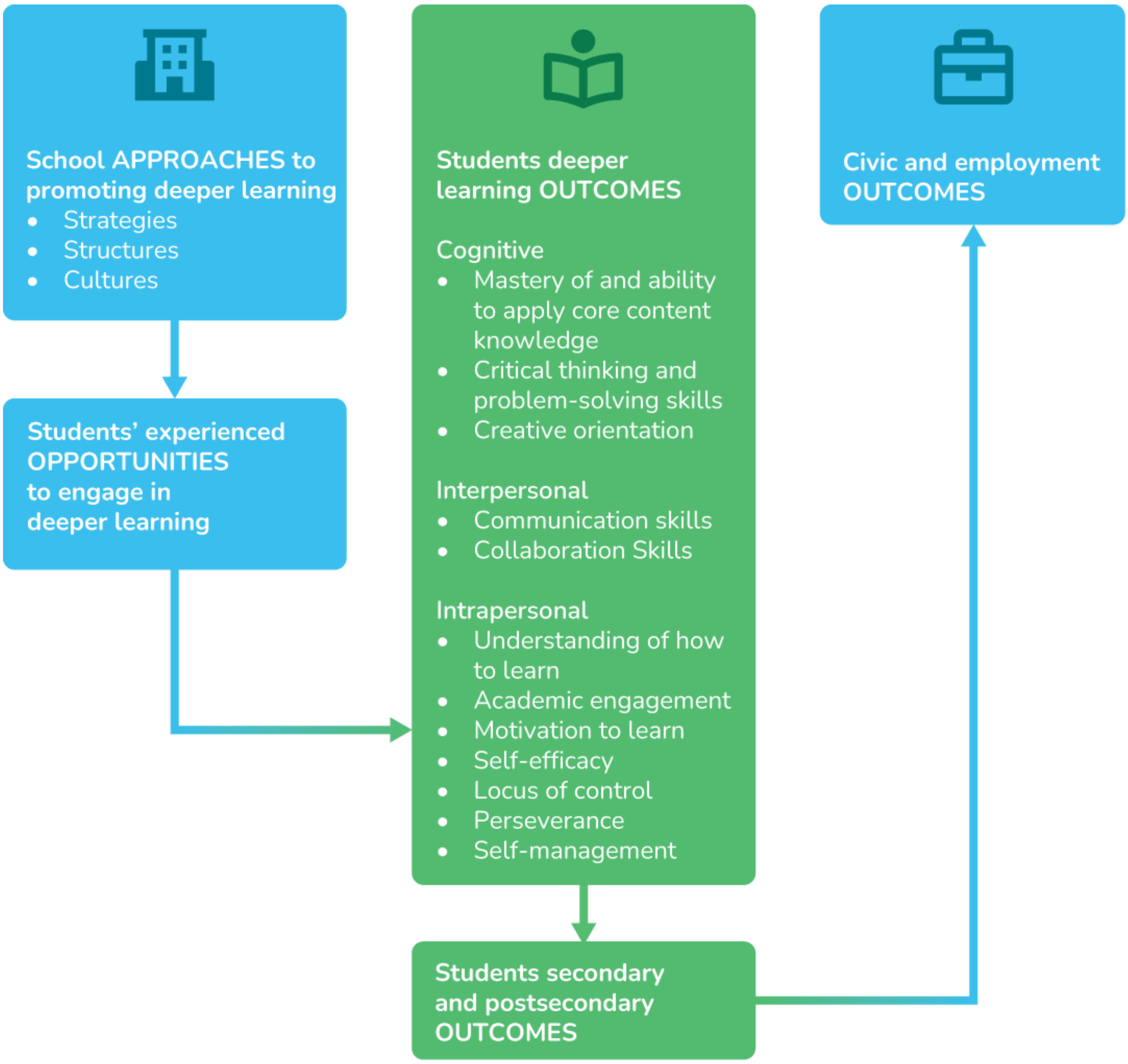

Figure 1: The process for assessing the impact of Deeper Learning Approaches implemented in a network of US schools. Many of the intrapersonal outcomes shown in the diagram align with the sixth deeper learning competency—the development of academic mindsets (AIR, 2014).

Researchers in the field of deeper learning argue that approaches focused on developing such competencies can improve outcomes for all learners, including those from traditionally underserved groups and those who have not previously experienced educational success. The abbreviated theory of action for the deeper learning initiative (shown in Figure 1) delineates the key hypothesized relationships between school approaches to promoting deeper learning, opportunities to engage in deeper learning, and outcomes. Figure 1 provides additional detail related to the learners' outcomes. The research team has focused on a key question about student outcomes: Did learners who attended participating network high schools perform better on tests of cognitive competency, report higher levels of interpersonal and intrapersonal competencies, or attain higher rates of high school graduation and college enrollment than they would have had they not attended the network schools? The research team found that learners who attended participating network high schools that explicitly focused on deeper learning experienced superior outcomes compared to learners who attended non-network comparison high schools. Key takeaways include the following:

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1. *On average, students who attended the network schools in the study* ***achieved higher scores on the OECD PISA-Based Test for Schools*** *(PBTS) a test that assesses* ***core content knowledge and complex problem-solving skills*** *than did similar students who attended non-network high schools. Students who attended network schools scored higher on all three PBTS subjects tested (reading, mathematics, and science). They also earned higher scores on the state English Language Arts (ELA) and mathematics tests.*

2. *Students who attended participating network schools* ***reported more positive interpersonal and intrapersonal outcomes*** *than students who attended non-network schools. In particular, they reported*

***higher levels of collaboration skills, academic engagement, motivation to learn, and self-efficacy**. There were **no significant differences** between students who attended network and non-network schools **on reported creative thinking skills, perseverance, locus of control, or self-management.***

3. *Students who attended participating network schools were **more likely to graduate from high school on time** (within four years of entering Grade 9) than were students who attended non-network high schools. The graduation rate among students who attended network schools was estimated to be about 9 percentage points higher than among similar students who attended non-network schools.*

4. *Students who attended participating network schools and non-network schools had **similar rates of enrollment in postsecondary institutions overall**. However, students who attended network schools were more likely to enroll in four-year institutions and in selective institutions.*

5. *Although there were significant positive effects of attending a network school averaging across the pairs of network and non-network schools in our sample, for many outcomes-for example, PTS mathematics scores--the effects of attending a network school varied significantly across individual pairs of schools.*

6. *Attending a network school had similar benefits for students who entered high school with low achievement and those who entered with high achievement, particularly for the test score and high school graduation outcomes. However, while attending a network school increased the postsecondary enrollment rate of students who entered high school with low achievement, it had no effect on the postsecondary enrollment rate of students who entered with high achievement.*

## 1.3 PLAYING WITH PROTONS GOES DIGITAL DEEPER LEARNING PARADIGM

Playing With Protons Goes Digital was conceived as a project to a) present frontier physics research topics, as a catalyst for the **effective interaction between Art and STEM disciplines towards promoting learners' Deeper Learning**, b) present a new vision for teaching outlining strategies for **how Educators' roles and conditions can support and enable deeper learning for learners** and c) to support and **facilitate the aforementioned approaches with meaningful digital technologies**, such as advanced interfaces, learning analytics, visualization dashboards and Augmented/Virtual reality applications. Playing With Protons Deeper Learning Paradigm incorporates the idea that a range of competences and their orchestrated skillful application leads to STEM mastery. To accomplish a **holistic assessment of STEM mastery** within the deeper learning paradigm in science education, we will develop standardized assessment tools that cover intellectual and motivational ability. Especially communicational competences (e.g., collaborative problem solving) are essential elements of our deeper learning paradigm and can relate to both, motivational and intellectual ability.

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*Our assessment approach will assess a broad range of abilities necessary for deeper learning with* ***standardized scales****. Apart from its use in the evaluation of the educational interventions, most instruments will be applicable to any other deeper learning intervention, and thus, at the first time allow building an empirical basis to compare different deeper learning interventions. This possibility in turn is essential for an* ***evidence-based promotion and development of the deeper learning paradigm.***

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To accomplish a **comprehensive assessment of STEM mastery** within the deeper learning paradigm in science education, we will develop standardized assessment instruments that cover intellectual and motivational abilities. The project's core educational method (i.e., inquiry based and project-based learning) is based on the six pedagogical principles that elaborately represent deeper learning abilities that are mentioned in common definitions (see e.g., The William and Flora Hewlett Foundation, 2016). Inquiry based learning is a method that evolves **Engaging** Learners; **Exploring** Contextual Issues; **Explaining** Scientific Concepts and Inquiry Abilities; **Elaborating** Knowledge and Abilities in New Contexts; **Evaluating** Learners' Knowledge and Abilities (Bybee 2000). This framework builds on a four-strand model developed to capture what it means to learn science in school settings by adding two additional main strands incorporated for informal science learning, reflecting a special commitment to interest, personal growth, and sustained engagement that is the hallmark of informal settings. These principles will guide the overall project and that are at the core of the deeper learning paradigm (see Table 1).

The six pedagogical principles of deeper learning in connection to STEM education can be translated into six crucial **intellectual and motivational abilities**. While (1) understanding scientific content and knowledge, (2) engaging in scientific reasoning, as well as (3) reflecting on science represent intellectual abilities (4) using the tools and language of science (collaborative problem solving), (5) sparking interest and excitement, and (6) identifying with the scientific enterprise rather represent motivational abilities. However, our research will be the first to fully implement and empirically test the deeper learning paradigm. Regarding the interrelations among the various intellectual and motivational abilities, we will explore them in an evidence-based manner without previously analytically derived hypotheses. For that matter, we need to assess our pupils' abilities before, after, and especially throughout the intervention.

| **Strands – Pedagogic Principles** | **Educational Objectives** |
|---|---|
| **Sparking Interest and Excitement** | *Experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world.* |
| **Understanding Scientific Content and Knowledge** | *Generating, understanding, remembering, and using concepts, explanations, arguments, models, and facts related to science.* |
| **Engaging in Scientific Reasoning** | *Manipulating, testing, exploring, predicting, questioning, observing, analyzing, and making sense of the natural and physical world.* |

| | |
|---|---|
| **Reflecting on Science** | *Reflecting on science as a way of knowing, including the processes, concepts, and institutions of science. It also involves reflection on the learner's own process of understanding natural phenomena and the scientific explanations for them.* |
| **Using the Tools and Language of Science** | *Participation in scientific activities and learning practices with others, using scientific language and tools.* |
| **Identifying with the Scientific Enterprise** | *Coming to think of oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science.* |

**Table 1:** The main Pedagogic Principles and the Educational Objectives for the design and implementation of the Deeper Learning Paradigm in the framework of Playing With Protons Goes Digital project.

A successfully developed, tested, and applied comparable competence model that consists of motivational and intellectual abilities in the domain of environmental education has already been developed (Kaiser, Roczen, & Bogner, 2008; Roczen et al., 2014). Based on this competence model we found that the intellectual components (i.e., action-related knowledge, system knowledge, and effectiveness knowledge) converge for people with higher overall knowledge and higher motivational ability (Frick, Kaiser, & Wilson, 2004). Relying on this experience, the project will develop technology-based scales and assessment instruments for each of the six motivational and intellectual abilities in STEM that relate to the six pedagogical principles. Thus, the intervention design (**O1**), and the assessment framework (**O4**) will form the basis for the development of objective and standardized student assessment instruments to meet the challenges of the Playing With Protons Goes Digital project.

In the framework of the Playing With Protons Goes Digital project the main objective of the evaluation is to ensure a continued learning process based on the deeper learning paradigm that addresses not just intellectual abilities but also motivational abilities (see Figure 2). Our deeper learning paradigm incorporates the idea that a range of abilities and their orchestrated skillful application leads to STEM mastery. Considering our approach to develop STEM mastery, that is, students projects which include a multitude of options to broadly improve deeper learning abilities, we emphasize its strong innovative character that leads to a challenging evaluation procedure. An evaluation that only concentrates on intellectual abilities and STEM specific knowledge that can also be acquired differently (i.e., chemical composition of the stars) would be far too short sighted to assess all the abilities involved in deeper learning (see e.g., National Research Counsil, 2012; Pellegrino, Wilson, Koenig, & Beatty, 2014).

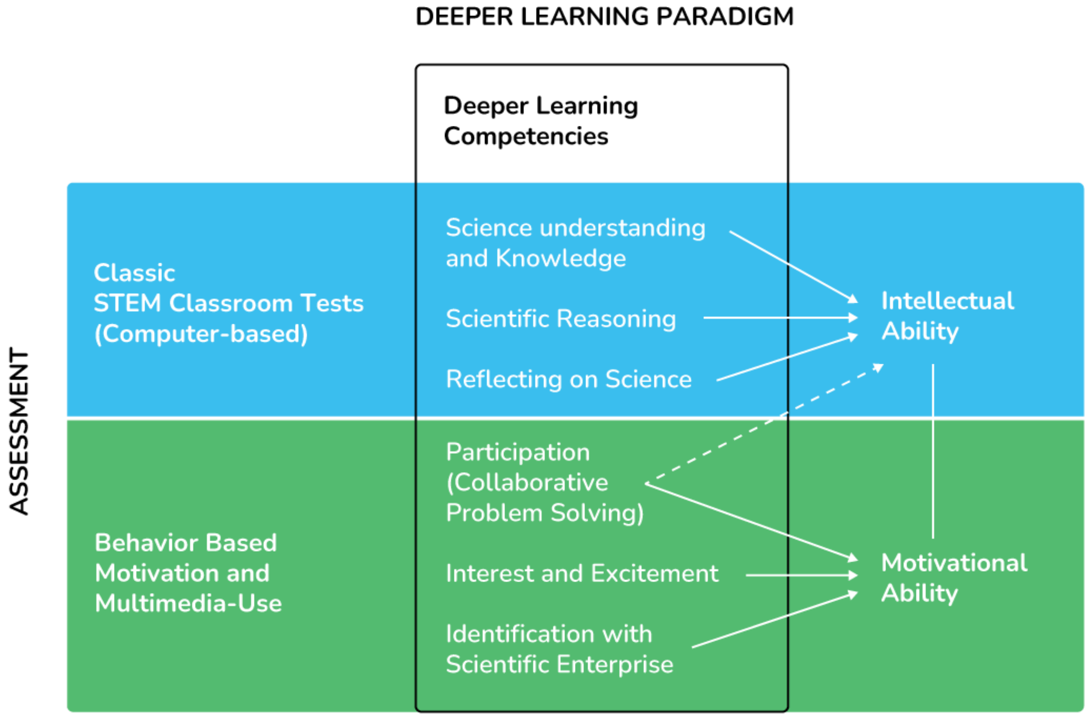


**Figure 1:** The Deeper Learning Paradigm in Playing With Protons Goes Digital Project.

Thus, we will develop and apply **technology-based assessment instruments** that allow to universally assess all essential abilities that are central to deeper learning. The assessment educational data (performance indicators) generated by the proposed tools can be utilized for creating learners' Deeper Learning competence profiles (see Chapter 2). The emerging research field of Learning Analytics can provide a promising approach to introduce such a profiling process for learners' Deeper Learning competences, which could, in turn, feed visualization dashboards to facilitate the educator to have an overview of the learners' competence level and development. This kind of overview can facilitate

Educators' evidence-based coaching, teaching planning and/or classroom delivery (Kumar et al., 2015). For this purpose, we will concentrate the learners' assessment on the educational outcome that our pedagogical method, which fosters the core abilities involved in deeper learning – proposes to achieve.

## 1.4 PLAYING WITH PROTONS GOES DIGITAL PEDAGOGICAL CHALLENGES

In this section we focus on the relationship in the theory of action between school approaches to promoting deeper learning (including strategies, structures, and cultures) and the *opportunities* that learners must engage in deeper learning. Offering such opportunities in not a simple task in current school environments. So, Playing With Protons Goes Digital project has to deal with significant challenges in pedagogy. The NMC HORIZON 2015 Report on K-12 (see Figure 3) presents a series of challenges for K-12 education. Some of them (according to the Report) will have short term impact (Rise of STEAM) while Deeper learning seems to consider as a major challenge for policies and school practice. The Playing With Protons Goes Digital aims to add its contribution at these developments in education. It must meet challenges that are scanning the full spectrum: **Rise of STEAM**, **Learners as Creators of Educational Content**, **Collaborative Learning**, and **Deeper Learning in STEM**. We must note that the Rise of STEAM in schools in Europe (and beyond) is a quite demanding challenge. In this section we are focusing to the other three main pedagogical challenges, which will offer in return the opportunities to engage our learners to deeper learning.

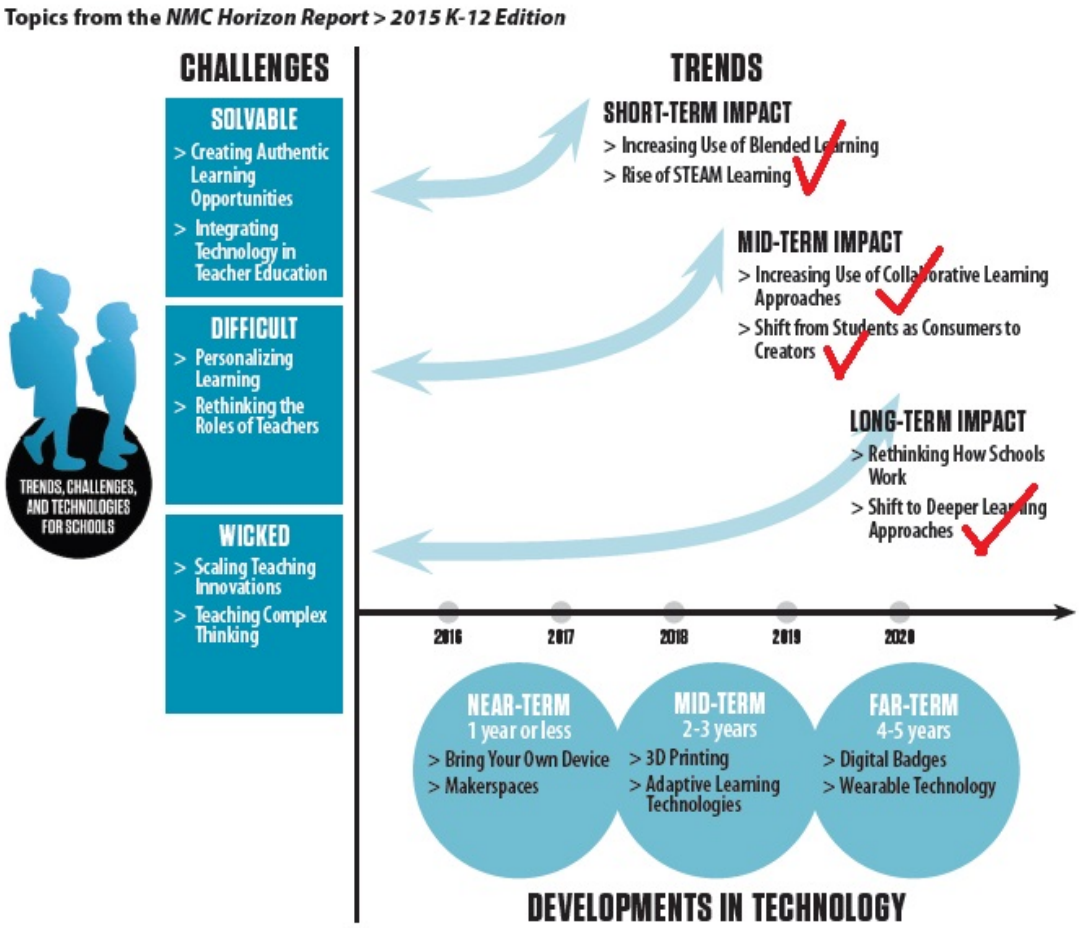


**Figure 2:** The main challenges for the next years in K-12 education (NMC, 2015)

## Shift from Learners as Consumers to Creators

According to the NMC HORIZON Report 2015 K-12 "a shift is taking place in schools all over the world as learners are exploring subject matter through the act of creation rather than the consumption of content". Today a vast array of digital applications is available to support this transformation in K-12 education; indeed, the growing accessibility of mobile technologies is giving rise to a whole new level of comfort with producing media and prototypes. Many Educators believe that honing these skills in learners can lead to deeply engaging learning experiences in which learners become the authorities on subjects through **investigation**, **storytelling**, and **production**. Playing With Protons Goes Digital project will have a significant contribution in this trend. The Playing With Protons Goes Digital AR platform will provide the means and the tools along with the necessary collaborative and personalization functionalities to introduce learners in extended episodes of deep STEM learning combined with art related activities (music, movie making, 3D design). The platform will introduce learners in a **progressive exploration of the different technologies** that can be accommodated from the system, from simple text and video uploading to advanced augmentations of learners' artifacts. As learners become more active producers and publishers of educational resources, intellectual property issues will become a key component to be discussed and explored further.

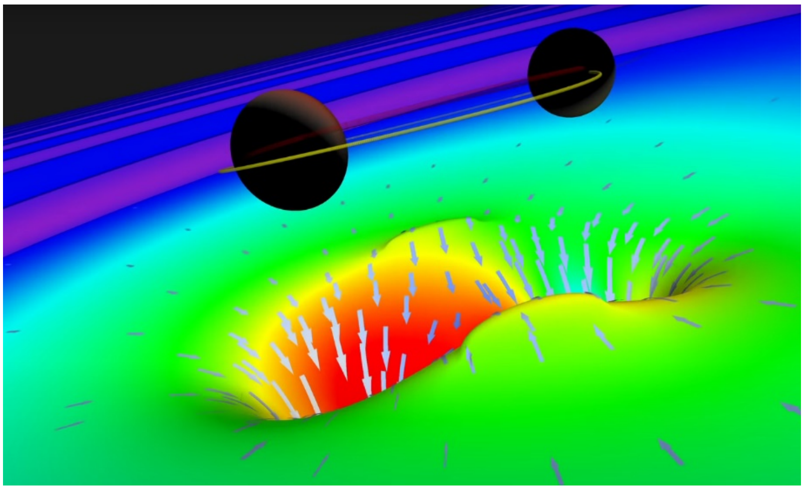

**Figure 3:** Students will be able to visualize complex phenomena and enrich them with augmentations videos and sounds. Here the collision of two black holes is simulated.

## Increasing Use of Collaborative Learning Approaches

Collaborative learning, which refers to learners or Educators working together in peer-to-peer or group activities, is based on the perspective that learning is a social construct. The Playing With Protons Goes Digital approach involves activities that are focused around four principles: **placing the learner at the center**, emphasizing **interaction and doing**, **working in groups**, and **developing solutions to real-world problems** in the framework of the creation of the story. Collaborative learning models are proving successful in improving student engagement and achievement, especially for **low performing learners**.

## Shift to Deeper Learning Approaches

Deeper learning combines the **goals of standardized testing** with **soft skills** such as **mastering communication**, **collaboration**, and **self-directed learning**. The goal is to assess a student's performance through more than just test scores. Project-based learning and inquiry-based learning have proven their efficiency in fostering more active learning experiences, both inside and outside the classroom. As technologies, such as tablets and smartphones are more readily accepted in schools, Educators are leveraging these tools to connect the curriculum with real life applications. These approaches are decidedly more student-centered, allowing learners to take control of how they engage with a subject. In advance examples of this trend, learners can brainstorm solutions to pressing local and global problems and begin to implement them in their communities. Playing With Protons Goes Digital project supports deeper learning in STEM by implementing **project-based** and **inquiry-based** approaches in the framework of extended multidisciplinary activities in the school curriculum and beyond.

**Project-based Learning:** Project-based learning is a deeper learning approach that is seen to address gaps in science education. Project-based learning is stated to have several benefits that can enhance teaching and learning; they include **providing real world relevance**, **longer retention,** and **ability to apply knowledge of lessons learned**, **preparation for the 21st century work environment**, and exposure to **using technology to solve problems**. These are the main characteristics of the Playing With Protons Goes Digital approach. In the framework of the project learners will work in groups for an extended period to develop their own AR artifact and to present it to their classroom or the school in the framework of an event. Learners will use the platform collaboratively, they will design, construct the scenery, they will take photos, they will collect data, they will organize short theatrical performances and they will video captured their activities to present it as an integrated activity.

**Inquiry-based Learning:** Inquiry-based learning is proving to be an effective pedagogical approach to deeper understanding of curriculum. Inquiry-based learning involves learners constructing their own knowledge based on personal experiences and explorations. It is a method of learning by doing that parallels the work of scientists as they pursue scientific inquiry. With appropriate guidance, research has shown that inquiry-based activities can improve student learning in a range of subjects beyond STEM. By implementing the Playing With Protons Goes Digital project Educators in the participating schools will formulate a classroom community of inquiry to show learners how to integrate technological resources to engage in new forms of communication and expression.

## 1.5 TEACHING FOR DEEPER LEARNING

Deeper Learning: How Eight Innovative Public Schools are Transforming Education in the 21st Century (2014) by Martinez and McGrath identifies six strategies and pedagogical practices common across the schools committed to deeper learning outcomes for learners. Their analysis found that to prepare learners for success in the 21st century, Educators must:

- Empower learners
- Contextualize knowledge
- Connect learning to real world experiences
- Extend learning beyond the school
- Inspire learners by customizing learning experiences
- Purposefully incorporate technology to enhance learning

### Empowering learners

Educators who focus on deeper learning see their first responsibility as empowering learners as learners. For this reason, they use pedagogical approaches that help learners become self-directed and responsible learners rather than passive rule followers. The centerpiece of instruction is helping learners develop an understanding of learning as a complex and ongoing process that entails seeking feedback, revising work and regularly reflecting on what one has produced, as well as on the choices and decisions made throughout the learning process. “Revision toward mastery” is therefore a main feature of the culture and the language used by Educators committed to deeper learning (Lenz, 2015). Educators provide feedback, as well as opportunities for learners to receive feedback from peers, reinforcing the idea that learning does not end with their first effort. Improving their work through rounds of feedback, revision and reflection encourages learners to better understand the amount of effort required to produce high quality work.

### Contextualize knowledge

Educators who work to achieve deeper learning student outcomes also contextualize knowledge so it is coherent as a way to help learners acquire content knowledge. Educators use guiding questions, common themes, and big ideas to provide a context for every assignment, classroom activity, and project. Educators are involving learners in project that are relevant to them and to the local communities. Educators also can involve learners' projects related to global challenges. Educators often work together across multiple subjects to design integrated learning experiences to connect their otherwise separate subject-specific content.

### Connect learning to real issues and settings

Educators who focus on developing deeper learning competencies connect learning to real issues and settings to make it more meaningful for learners. Educators ensure that there are frequent opportunities for learners to experience workplace conditions and expectations and address real world challenges and problem solving by interacting with professionals and experts in relevant fields, taking on a professional role when doing a project, or by connecting historical events to current issues.

### Extend learning beyond the school

In addition to connecting to the "real" world, deeper learning-focused educators find ways to extend learning beyond the school and construct powerful student learning experiences in a range of settings. As a result of long-term formal and informal relationships with local businesses, institutions, and community groups, the classroom walls drop away and the entire community becomes an annex of the school in which learners have access to rich content, outside experts, additional resources, an authentic place and context for learning, and work-based experiences.

### Inspire learners by customizing learning experiences

Educators who focus on deeper learning inspire learners by customizing learning experiences. Educators are intentional in establishing strong relationships with learners for the purpose of finding what will ignite their interest to pursue their own learning. Educators use independent projects to both customize learning and provide inspiration for all of their learners.

### Use technology in service of learning

Educators who focus on developing deeper learning competencies use technology in service of learning. Educators purposefully incorporate technology to enhance, rather than automate learning; regularly employ technology tools to support student learning and to engage learners in their own education; and shift their role away from being the sole gatekeeper to knowledge.

For teaching to shift to facilitate powerful learning experiences like the ones described above - where learners are empowered and inspired and learning is contextualized, connected to real life, wired, and extended beyond school - the role of the educator must change to that of learning strategist. For an educator to be a coach of learning, he or she must fluidly shift among a range of roles, including learning designer; facilitator; networker; and an advisor who coaches, counsels, mentors, and tutors depending on what is most needed to promote student learning.

Therefore, it is important for educators to recognize that there are **key conditions that support deeper learning outcomes and strategies**, and that these conditions are sequential and rely on and build upon one another. The cornerstone condition is **a school-wide culture** that focuses on learning and promotes **the belief that everyone is collectively responsible for student outcomes**. These are two different concepts, and both are critically important.

## Establish a new learning culture

First, a learning culture must be established that values the need to learn, as well as learners' need to learn how to learn, to become self-directed, and to develop an academic mindset. This culture is established or signaled most commonly through the creation of a clear and visible set of core values that are then reflected in the design of the school, the way in which learners are introduced to and oriented to the school, what is assessed, and the consistent language used across the school, including what is posted on the walls. An understanding and reflection of these core values can be seen in everything from the language that Educators and learners use to talk about learning to the way the school interacts with the community.

## Create shared responsibility for student learning

The corresponding condition in support of teaching for deeper learning is a culture in which everyone is collectively responsible for student learning. This culture has to be purposefully established for learners and educators alike, and is most commonly developed by building relationships that ensure learners are known well by both adults and peers, and that there are regular and systemic opportunities for frequent conversations among educators, learners, peers, and other adults.

## Establish a culture of trust and professionalism

Furthermore, it is important to establish a culture of trust and professionalism as a condition that supports deeper learning. The shift in culture is critical to making sure educators feel supported and empowered to take on new roles, and to ensure that daily work and interactions are aligned to the deeper learning mission. Trust empowers individuals to be their best selves and creates a sense of shared accountability between and among the staff. Shared accountability can encourage greater feelings of trust among educators and between educators and principals. School heads who trust educators and treat them as professionals may also invite educators to share in the leadership of the school with them, meaning educators have substantial influence on school-based decisions, especially around issues of teaching and learning. Educators feel more comfortable wearing multiple hats—formally and informally assuming roles such as grade-team coordinator, educator mentor, educator leader, and coach. In this new paradigm, educators also often take on responsibilities many principals save for themselves, such as hiring staff, creating school schedules, developing partnerships with out of school organizations or businesses, and even dealing with funders. In a culture of trust and professionalism, school heads value their educators' vast experiences and wealth of knowledge and want them to be active participants in the construction and tailoring of professional development. Because educators design their own professional development, they are very engaged and work productively with their colleagues to ensure that professional development is growth-driven, collectively constructed, context specific, and embedded in the school.

## Preserve time for educators to collaborate

These shifts in culture and roles require settings that foster deeper learning outcomes and establish and respect time for educators to collaborate. During this collaboration time, Educators can draw upon each other's expertise to design or revise meaningful learning experiences for learners; address problems impacting the classroom and the school at large; and strategize how to improve their individual practice and student learning. Structured opportunities to work together can take the form of educator-directed and school embedded professional development by peers or third parties on how to use specific pedagogical approaches. They can focus on feedback from classroom observations from instructional coaches or teaching peers on one another's teaching practices. Educators can also use their structured time together to identify and share the technology tools, apps, or resources they have found to assess learners for mastery of content and critical thinking as well as other skills and personalize instruction to meet the unique learning needs of each student.

In this chapter we have described the **Playing With Protons Goes Digital Deeper Learning Paradigm** and we have tried to summarize the main challenges to introduce the project in school settings across Europe and the characteristics of teaching for Deeper Learning in order to make sure that the participating schools and Educators are fully realizing the different aspects and conditions of the proposed intervention. Now we need to define in practical terms for the educators the evidences of Deeper Learning in their classrooms. To do that we will describe the Learners Deeper Learning Profiles by defining the partial abilities of the key deeper learning competencies in the form of educational objectives and outcomes. This will be presented in Chapter 2 of the current document.

# 2

# DEEPER LEARNING COMPETENCIES AND LEARNERS PROFILES

# 2 DEEPER LEARNING COMPETENCIES AND LEARNERS PROFILES

As presented earlier, deeper learning can be envisaged as an umbrella term for the skills and knowledge that learners must possess to succeed in 21st century jobs and civic life. At its heart is a set of competencies learners must master to develop a keen understanding of academic content and apply their knowledge to problems in the classroom and on the job.

The deeper learning framework according to the on developed by The William and Flora Hewlett Foundation (2013) includes six competencies that are essential to prepare learners to achieve at high levels. These competencies form the basis of the Playing With Protons Goes Digital Deeper Learning Competence Framework.

The foundation of deeper learning is mastery of core academic content, whether in traditional subjects such as mathematics or in interdisciplinary fields which merge several key fields of study. Learners are expected to be active participants in their education. Ideally, they are immersed in a challenging curriculum that requires them to seek out and acquire new knowledge, apply what they have learned, and build upon that to create new knowledge.

Cognitive research shows that learners learn more when they are engaged in their studies and see them as important. The brain functions by organizing information into databases where things that relate to one another are connected. It determines what is worth holding onto, discarding information it considers useless. At the same time, it organizes for future reference information that is tapped frequently to accomplish important tasks.

The typical worksheet, drill-and-memorize, and test preparation approach to classroom teaching makes it difficult for learners to retain the myriad bits of information they encounter during the school year. More effective is an instructional method that requires learners to use important information repeatedly in complex and meaningful ways such as writing papers or completing projects.

Deeper learning activities should draw upon a clearly defined knowledge base to which learners have previously been exposed or to which they will be introduced systematically in the context of their academic work. Activities that are not linked the development of academic content knowledge and skills should be viewed with caution. In this chapter, we will present the partial abilities (described in the form of partial abilities) that will describe the Learners Deeper Learning Profiles.

## 2.1 LEARNERS DEEPER LEARNING PROFILES

### Master core academic content

Students develop and draw from a baseline understanding of knowledge in an academic discipline and can transfer knowledge to other situations.

The following abilities describe the profile of the learners who have succeed mastery on core academic content:

- *Learners understand key principles and relationships within a content area and organize information in a conceptual framework.*
- *Learners learn, remember, and recall facts relevant to a content area.*
- *Learners have procedural knowledge of a content area and know how content knowledge is produced and how experts solve problems.*
- *Learners know and are able to use the language specific to a content area.*
- *Learners extend core knowledge to novel tasks and situations in a variety of academic subjects.*
- *Learners learn and can apply theories relevant to a content area.*

- *Learners enjoy and are able to rise to challenges requiring them to apply knowledge in non-routine ways.*

- *Learners apply facts, processes, and theories to real world situations.*

## Think critically and solve complex problems.

Students apply tools and techniques gleaned from core academic subjects to formulate and solve problems. These tools include data analysis, statistical reasoning and scientific inquiry as well as creativity, nonlinear thinking, and persistence.

Deeper learning activities require learners to draw information from knowledge they have acquired and then do something meaningful with it. Because the brain must develop the internal wiring necessary to process information efficiently in non-routine ways, deeper learning activities should be structured to give learners multiple opportunities, over time, to apply knowledge in a range of challenging tasks. In essence, the learner moves from the novice to the expert level within the sphere of knowledge and expertise in question. This requires a range of strategies for processing information in sophisticated ways. Those strategies vary somewhat based on the subject area and nature of the activity, but all involve a commitment to systematic thought and analysis. There has been substantial research on the development of assessment methods for individual problem solving (the focus of PISA 2012), but work in assessment and training methods for collaborative problem solving (which is expected to be the case in Playing With Protons Goes Digital) is much less developed. As such, there are no established reliable methods for large-scale assessments of individuals solving problems in a collaborative context and no existing international assessments in wide use. According to PISA 2015, collaborative problem-solving competency is the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution. In this and in the next section we are describing the partial abilities that could define the collaborative problem-solving competence. The following abilities describe the profile of the learners who have succeed in thinking critically and solving complex problems:

- *Learners are familiar with and able to use effectively the tools and techniques specific to a content area.*
- *Learners formulate problems and generate hypotheses.*
- *Learners identify data and information needed to solve a problem.*
- *Learners apply tools and techniques specific to a content area to gather necessary data and information.*
- *Learners evaluate, integrate, and critically analyse multiple sources of information.*
- *Learners monitor and refine the problem-solving process as needed, based on available data.*
- *Learners reason and construct justifiable arguments in support of a hypothesis.*
- *Learners persist to solve complex problems.*

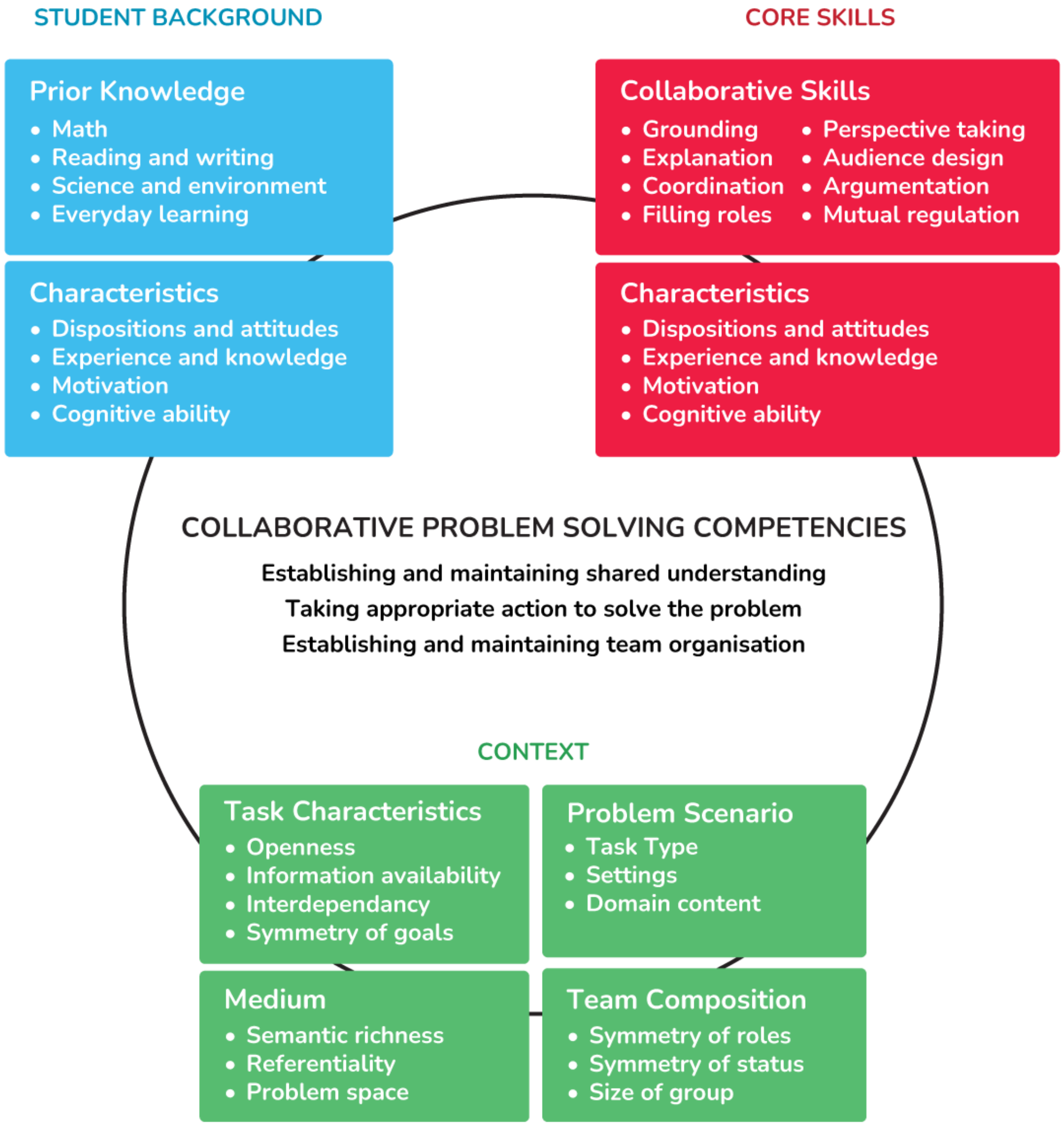


Figure 5: Overview of factors and processes for Collaborative Problem Solving in PISA 2015.

## Work collaboratively

Learners cooperate to identify and create solutions to academic, social, vocational and personal challenges.

The following abilities describe the profile of the learners who have succeed in working collaboratively to solve complex problems:

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- *Learners collaborate with others to complete tasks and solve problems successfully.*
- *Learners work as part of a group to identify group goals.*
- *Learners participate in a team to plan problem-solving steps and identify resources necessary to meet group goals.*
- *Learners communicate and incorporate multiple points of view to meet group goals.*

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## Communicate effectively

Learners clearly organise their data, findings and thoughts. The following abilities describe the profile of the learners who have succeed in communicating effectively:

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- *Learners communicate complex concepts to others in both written and oral presentations.*
- *Learners structure information and data in meaningful and useful ways.*
- *Learners listen to and incorporate feedback and ideas from others.*
- *Learners provide constructive and appropriate feedback to their peers.*

- *Learners understand that creating a quality final communication requires review and revision of multiple drafts.*

- *Learners tailor their message for the intended audience.*

## Learn how to learn

Learners monitor and direct their own learning. Deeper learning requires a broader range of conscious learning behaviours from learners than traditional schoolwork. They must accept responsibility for expending the time and energy necessary to think about a task, select the proper learning strategies, and judge how well those strategies are working. When learners encounter difficulty or setbacks, deeper learning requires that they diagnose the type of difficulty they are facing, select appropriate strategies to resolve the difficulty, and continue forward toward their learning goal. In addition, deeper learning expects learners to be able to meet shared goals with others as well as to engage in the self-reflection necessary to continue learning throughout their lives.

The following abilities describe the profile of the learners who have succeed in developing an understanding on how to learn:

- *Learners set a goal for each learning task, monitor their progress towards the goal, and adapt their approach as needed to successfully complete a task or solve a problem.*

- *Learners know and can apply a variety of study skills and strategies to meet the demands of a task.*

- *Learners monitor their comprehension as they learn, recognize when they become confused or encounter obstacles, diagnose barriers to their success, and select appropriate strategies to work through them.*

- *Learners work well independently but ask for help when they need it.*

- *Learners routinely reflect on their learning experiences and apply insights to subsequent situations.*

- *Learners are aware of their strengths and weaknesses, and anticipate needing to work harder in some areas.*

- *Learners identify and work towards lifelong learning and academic goals.*

- *Learners enjoy and seek out learning on their own and with others.*

- *Learners anticipate and are prepared to meet changing expectations in a variety of academic, professional and social environments.*

- *Learners delay gratification, refocus after distractions, and maintain momentum until they reach their goal.*

- *Learners use failures and setbacks as opportunities for feedback and apply lessons learned to improve future efforts. Learners care about the quality of their work and put in extra effort to do things thoroughly and well.*

- *Learners continue looking for new ways to learn challenging material or solve difficult problems.*

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## Develop academic mindsets

Deeper learning requires learners to develop positive attitudes and beliefs about themselves in relation to academic work. Academic mindsets are the motivational components that influence learners' engagement in learning. In turn, engagement in deeper learning reinforces positive academic mindsets. Learners with strong academic mindsets readily put in effort to learn and persist in the face of difficulty. They make use of cognitive, metacognitive, and selfregulatory strategies because they care about learning and are purposeful in doing what is required to succeed. It must be noted that this competence is mainly refer to upper high school learners who are about to start their university courses. In the case of Playing With Protons Goes Digital we will explore in detail the contribution of this competence to the deeper learning profiles of the learners. As we will discuss later we will allocate a quite low weight to the contribution of this competence to the learners deeper learning profile.

Learners develop positive attitudes and beliefs about themselves as learners and increase their academic perseverance and prompt them to engage in productive academic behaviours. Learners are committed to seeing work through to completion, meeting their goals, and doing quality work, and thus search for solutions to overcome obstacles.

The following abilities describe the profile of the learners who have succeed in developing an understanding that they belong in an academic community:

- *Learners feel a strong sense of belonging within a community of learners and value intellectual engagement with others.*
- *Learners understand learning as a social process and actively learn from one another and support each other in pursuit of learning goals.*
- *Learners readily engage in the construction of meaning and understanding through interaction with peers.*

The following abilities describe the profile of the learners who have succeed in developing an understanding that they can succeed at this:

- *Learners trust in their own capacity and competence and feel a strong sense of efficacy at a variety of academic tasks.*

- *Learners see themselves as academic achievers and expect to succeed in their learning pursuits.*

The following abilities describe the profile of the learners who have succeed in developing an understanding that their ability and competence grow with their effort:

- *Learners believe that hard work will pay off in increased knowledge and skills.*
- *Learners are motivated to put in the time and effort needed to build a solid knowledge base and to accomplish important goals.*

The following abilities describe the profile of the learners who have succeed in developing an understanding that this work has value for them:

- *Learners perceive the inherent value of content knowledge and of learning and developing skills.*
- *Learners see the relevance of schoolwork to their lives and interests.*
- *Learners understand how work they do now will benefit them in the future.*
- *Learners know that future learning will build upon what they know and learn today.*

This chapter has described the Learners' Deeper Learning Profiles. In the next chapter, we are providing the framework for the design of innovative curricula that support the creation of deeper learning conditions in the science classroom.

# 3

# PLAYING WITH PROTONS GOES DIGITAL VISION

## TOWARDS 21ST CENTURY CURRICULA

# 3 PLAYING WITH PROTONS GOES DIGITAL VISION: TOWARDS 21ST CENTURY CURRICULA

The transformation of the classroom environment is important, but the development of innovative curricula is crucial in the proposed reform effort. Although science education is now recognized as being important for all throughout their compulsory schooling, it is hard to shake off the traditional image. It is little wonder, then, that current school science leaves many students untouched in respect of developing broad ideas of science that could help their understanding of things around them and enable them to take part in decisions as informed citizens of a world where science and technology are of ever-increasing significance. The plea for relevance is most often to be heard from students at secondary school level, where ideas to be learned are becoming more abstract than those encountered in primary school science. But the course of learning in science requires a progressive grasp of ideas that have wider application and hence are inevitably more abstract. Problems of understanding arise when these abstract ideas do not seem to be rooted in and connected to the more concrete experiences from which they should be built. At the primary level, activities generally begin from objects and events around; the context gives them reality and teachers strive to ensure that they are of interest to the children. The problem there is not so much lack of relevance as perceived by the children but the relevance of what they learn to building understanding that is useful not just for their secondary education but for the rest of their lives. There is an enormous range of possible topics and activities. How are teachers to choose those that make the best use of limited and precious learning time?

## 3.1 BIG IDEAS OF SCIENCE

In the Deeper Learning Classroom environment school curriculum should be much more than just a list of topics split in different subject domains. It should reflect the vision of the school for the learning experience of the students, an aggregate of knowledge content and practice intended to support a seamless acquisition of key skills with a concrete set of goals towards their integration as valuable members of their community. Curriculum should be organized not as standard set of disciplines but as an integration of the different domains under a common umbrella. Curriculum should be flexible to accommodate, in general, the different socio-cultural environment and particularly each student's specific needs. Cross-disciplinary connections should be established taking all these characteristics as a starting point and building towards an aggregate of different experiences where students will understand the natural world and acquire the necessary competences to thrive in this rapid changing era. Part of the solution to these problems is to conceive the goals of science education not in terms of the knowledge of a body of facts and theories but a progression towards key ideas which together enable understanding of events and phenomena of relevance to students' lives during and beyond their school years. We describe these as big ideas in science and in this section, we try to explain what we consider them to be and how best communicated. The mode of communication is crucial if we are to convey the links between ideas and experience, which is better preserved in narrative form than in a list of disconnected points. It is important also to show how ideas have their roots in students' early explorations so that teachers, even if not the students, are aware of the contribution of these activities to a developing picture of the scientific aspects of the world around.

It is not only science education than can be improved by anchoring facts and figures to unfolding themes. Historians are calling for specific events to be linked to narratives; similarly, there is a strong case for bringing together ideas from studying different phenomena in geography. The same could be said of many domains of knowledge, which exist as domains by virtue of possessing a core of knowledge, skills and attitudes but where, as in the case of science, the nature of this core is not made explicit. To express it in terms of the development of big ideas would surely provide a rationale and a framework for inclusion of topics and types of study within the school curriculum.

There can be no doubt that a reason for the current fragmentation of students' learning experiences in many domains is to be found in the form of assessment that is used. Conventional tests and examinations ask a series of disconnected questions which inevitably represent a selection, from the possible range, of those questions which can be reliably scored. Not surprisingly this encourages teaching of disconnected items of knowledge and how to give the 'right' answers. Further, the use of the results of assessment for high stakes decisions affecting students and teachers has implications for what is assessed and how.

When students and teachers are being judged on results of tests or examination, there is a premium on accuracy that leads to restricting what is included to learning outcomes where performance can be most easily marked as correct or incorrect. This tends to exclude outcomes that are more difficult to judge unequivocally as right or wrong, such as application of concepts, reasoning, understanding (as opposed to factual knowledge) and attitudes that are likely to influence future learning. Although some of the outcomes that are difficult to include in formal written examinations can be assessed through projects or course work, high stakes pressure leads to a narrow focus in such work on the aspects that are reflected in the assessment criteria. This 'disease' spreads to the primary school when testing is frequent and is used as a measure of teachers' or schools' performance. In extreme, this results in what is taught being determined by what is assessed rather than by what is of value in adding to a growing understanding of key ideas and development of reasoning skills and attitudes. It causes teachers to teach in a way that neither pleases them nor satisfies their students.

Unfortunately, policies of frequent external testing of all students persist, despite two decades of research which has given evidence of their negative impact and refuted the claim that 'testing raises standards'. However, it is not our purpose here to discuss further issues relating to assessment of students' achievement nor the related matter of how to evaluate the effectiveness of schools, except to point out that it is high time for considerable investment in developing new approaches to assessment that better reflect key ideas and skills in all subject domains.

Recent actions to reverse students' lack of interest in and enjoyment of science have focused on the approach to teaching. An inquiry-based approach is widely advocated and is being implemented in many different countries across the globe. Inquiry, well executed, leads to understanding and makes provision for regular reflection on what has been learned, so that new ideas are seen to be developed from earlier ones. It also involves students working in a way like that of scientists, developing their understanding by collecting and using evidence to test ways of explaining the phenomena they are studying. There is growing evidence that this has a positive influence on attitudes to science. However, it is optimistic to assume that change in pedagogy can be brought about without changing content or the curriculum. Inquiry-based teaching is demanding, both of teachers' skill and of time for teaching and learning. Inquiry-based learning can lead to greater depth in understanding but as it takes more time the corollary is that the breadth must be reduced. Thus, identifying big ideas in science is a natural, and indeed necessary, accompaniment to promoting inquiry-based science education.

The following list gives the brief summaries of the ideas that all students should have had opportunity to learn by the end of compulsory education. In Appendix I these ideas are expressed more fully in narrative form describing the progression towards them over the years of schooling.

## 3.2 IDEAS OF SCIENCE

### 1 All matter in the Universe is made of very small particles

Atoms are the building blocks of all matter, living and non-living. The behaviour and arrangement of the atoms explains the properties of different materials. In chemical reactions atoms are rearranged to form new substances. Each atom has a nucleus containing neutrons and protons, surrounded by electrons. The opposite electric charges of protons and electrons attract each other, keeping atoms together and accounting for the formation of some compounds.

### 2 Objects can affect other objects at a distance

All objects have an effect on other objects without being in contact with them. In some cases the effect travels out from the source to the receiver in the form of radiation (e.g. visible light). In other cases action at a distance is explained in terms of the existence of a field of influence between objects, such as a magnetic, electric or gravitational field. Gravity is a universal force of attraction between all objects however large or small, keeping the planets in orbit round the Sun and causing terrestrial objects to fall towards the centre of the Earth.

### 3 Changing the movement of an object requires a net force to be acting on it

A force acting on an object is not seen directly but is detected by its effect on the object's motion or shape. If an object is not moving the forces acting on it are equal in size and opposite in direction, balancing each other. Since gravity affects all objects on Earth there is always another force opposing gravity when an object is at rest. Unbalanced forces cause change in movement in the direction of the net force. When opposing forces acting on an object are not in the same line they cause the object to turn or twist. This effect is used in some simple machines.

## 4 The total amount of energy in the Universe is always the same but can be transferred from one energy store to another during an event

Many processes or events involve changes and require an energy source to make them happen. Energy can be transferred from one body or group of bodies to another in various ways. In these processes some energy becomes less easy to use. Energy cannot be created or destroyed. Once energy has been released by burning a fossil fuel with oxygen, some of it is no longer available in a form that is as convenient to use.

## 5 The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate

Radiation from the Sun heats the Earth's surface and causes convection currents in the air and oceans, creating climates. Below the surface heat from the Earth's interior causes movement in the molten rock. This in turn leads to movement of the plates which form the Earth's crust, creating volcanoes and earthquakes. The solid surface is constantly changing through the formation and weathering of rock.

## 6 Our solar system is a very small part of one of billions of galaxies in the Universe

Our Sun and eight planets and other smaller objects orbiting it comprise the solar system. Day and night and the seasons are explained by the orientation and rotation of the Earth as it moves round the Sun. The solar system is part of a galaxy of stars, gas and dust, one of many billions in the Universe, enormous distances apart. Many stars appear to have planets.

## 7 Organisms are organised on a cellular basis and have a finite life span

All organisms are constituted of one or more cells. Multi-cellular organisms have cells that are differentiated according to their function. All the basic functions of life are the result of what happens inside the cells which make up an organism. Growth is the result of multiple cell divisions.

## 8 Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms

Food provides materials and energy for organisms to carry out the basic functions of life and to grow. Green plants and some bacteria can use energy from the Sun to generate complex food molecules. Animals obtain energy by breaking down complex food molecules and are ultimately dependent on green plants as their source of energy. In any ecosystem there is competition among species for the energy resources and materials they need to live and reproduce.

## 9 Genetic information is passed down from one generation of organisms to another

Genetic information in a cell is held in the chemical DNA. Genes determine the development and structure of organisms. In asexual reproduction all the genes in the offspring come from one parent. In sexual reproduction half of the genes come from each parent.

## 10 The diversity of organisms, living and extinct, is the result of evolution

All life today is directly descended from a universal common ancestor that was a simple one-celled organism. Over countless generations changes resulting from natural diversity within a species lead to the selection of those individuals best suited to survive under certain conditions. Species not able to respond sufficiently to changes in their environment become extinct.

## 3.3 IDEAS ABOUT SCIENCE

### 11 Science is about finding the cause or cause of phenomena in the natural world

Science is a search to explain and understand phenomena in the natural world. There is no single scientific method for doing this; the diversity of natural phenomena requires a diversity of methods and instruments to generate and test scientific explanations. Often an explanation is in terms of the factors that have to be present for an event to take place as shown by evidence from observations and experiments. In other cases supporting evidence is based on correlations revealed by patterns in systematic observation.

### 12 Scientific explanations, theories and models are those that best fit the evidence available at a particular time

A scientific theory or model representing relationships between variables of a natural phenomenon must fit the observations available at the time and lead to predictions that can be tested. Any theory or model is provisional and subject to revision in the light of new data even though it may have led to predictions in accord with data in the past.

### 13 The knowledge produced by science is used in engineering and technologies to create products to serve human ends

The use of scientific ideas in engineering and technologies has made considerable changes in many aspects of human activity. Advances in technologies enable further scientific activity; in turn this increases understanding of the natural world. In some areas of human activity technology is ahead of scientific ideas, but in others scientific ideas precede technology.

### 14 Applications of science often have ethical, social, economic and political implications

The use of scientific knowledge in technologies makes many innovations possible. Whether or not particular applications of science are desirable is a matter that cannot be addressed using scientific knowledge alone. Ethical and moral judgments may be needed, based on such considerations as justice or equity, human safety, and impacts on people and the environment.

## 3.4 CURRICULUM CONTENT AND THE BIG IDEAS OF SCIENCE

By curriculum content we mean the particular topic or subject matter studied as a vehicle for students to achieve the ideas, skills and attitudes set out in a formal programme of study. Since there are numerous settings for the development of ideas about, for instance, forces and movement, food chains, or the insulating properties of different materials, there must be some way of choosing among possible topics and activities. The principles in Section 2 imply some criteria for selection: activities should promote enjoyment of scientific activity; sustain curiosity; be seen by students as interesting and relevant to their lives; and of course, develop scientific understanding, capabilities and attitudes. Further, a central part of the reason for identifying big ideas is for students to experience how science enables us to understand how the world works.

### Using content from the world around

Teachers generally instinctively recognise the need to capture the interest of their students and that this is best attempted through selecting content relating to a real or possible but hypothetical experience. Teachers of young children are expert at creating a story or an imagined situation as a setting for investigations – building a model house out of shoe boxes in the classroom as a context for exploring different materials that are used in real constructions or imagining how to keep warm on a cold and windy mountain as a reason for testing the insulating properties of different fabrics. For older students the pretence can be supplemented by real experience, through visits to power stations, water-treatment plants, recycling centres, etc. Not only can such visits motivate interest in how these essential services are provided, but they give students opportunity to see how science is applied in these processes.

Real world topics provide interest and motivation. The motivating link is important, particularly in an age where children have instant access to entertainment not only through television but also at any time on their mobile devices. But events and phenomena in the world around are usually too complex for students to be able to understand how they work by directly interacting with the actual events or phenomena. Although using real world contexts has many advantages – and there are certain phenomena that need to be studied in situ precisely because of the complexity – it can also be confusing. The considerable detail of actual events can obscure the characteristics that need to be identified to develop ideas that transfer to other settings.

Learners need help in giving attention to the critical (as opposed to the irrelevant) features of a complex problem and it should not be assumed that they are able to identify underlying and applicable relationships for themselves. So, to avoid confusion of working only in the field, we take the essence of the problem into the classroom or laboratory where ideas can be more directly tested and developed. Whether the context that motivates engagement is a story or a visit, the science is learned in a simplified version of reality in the classroom or laboratory where conditions can be controlled, and variables measured.

In this process it is important not to lose the link to things in the world around. Unless the crucial link back into the 'real' setting is maintained, there is a risk of the relevance of classroom-based activities being forgotten. So, there is a need for a balance between the richness and cognitive demands of too much information associated with real world contexts and study of specific selected aspects that help to make connections between different events and phenomena. Also important is regular discussion of how the findings of classroom inquiries are connected to the initial motivating context. Most significant for the development of bigger ideas are challenges to apply emerging ideas to new situations and to make connections with the ideas used to explain them.

## Ways of engaging with content

There are some topics that are best addressed through investigation and inquiry whilst others re more appropriately presented as an account of a scientific discovery or discussion of experiments or findings of current topical interest. All of these should be included in the selection of content linked to the big ideas. It is important for students to have opportunities for discussing how some ideas have changed in the history of science and the reasons for these changes. Extending such discussion to students' own investigations helps students to recognise the role of evidence in the development of understanding, advancing their progress towards big ideas about the nature of science and its applications. This is further helped by discussion of how applications of science have led to developments in, for instance, medicine, communications, and travel. Topics such as these generally engage students' interest and are key sources of motivation to develop their ideas about events and phenomena in the world around.

## Progression in engaging with content

It is possible to study the same events, habitats and phenomena at different times across the years of schooling as long as the ways in which the content is investigated take account of students' progression over time in the development of relevant ideas. This progression will vary from student to student according to their previous opportunities both in and out of school. A precise description of progress, applying to all students, is thus unrealistic but there are common trends that enable a broad description of what might be expected at various points as students move from preschool through primary and secondary education. These trends include:

- greater recognition that several factors need to be considered if phenomena are to be explained
- greater quantification of observations, using mathematics to refine relationships and deepen understanding
- increasing ability to consider that properties may be explained by features that are not directly observable
- more effective use of physical, mental and mathematical models.

The references here to increasing use of quantification of observations and models of relationships highlight the important role that mathematics takes in developing ideas in science through inquiry. Mathematics helps students to go beyond description in words. Organising data through representation in graphs, charts and tables helps students to notice patterns and make connections that develop their thinking about associations between variables, and to formulate hypotheses about causes that can be tested. Analysing data statistically enables students to make inferences about the probability of relationships and predictions. There is mutual benefit in coordinating science and mathematics education; mathematical tools help understanding in science and, at the same time, using data from science investigations helps in the developing appreciation of the range and application of these tools.

## 3.5 OVERVIEW

Having a consistent STEM methodology is a key factor in providing schools with a meaningful, effective and engaging science learning and teaching experience. However, human skills and competences go far beyond those related to science knowledge and practice. Human nature also evolves around tolerance, empathy, cooperation, and many other emotional, social and artistical skills. Considering this, it is a futile exercise to consider that STEM for itself will be enough to create humans that attend effectively to all aspects of the future of human society. The Big Ideas of Science are setting the right tone for the integration of science disciplines into a framework that is more holistic, interdisciplinary and more in line with our daily life's experiences. However, the full picture of the Deeper Learning Classroom is not there. The manifestation of our creativity, our perception of the world around us can only be complete if we can integrate the freedom to express ourselves, incorporate our feelings and materialize our vision according to our own experiences and acquired knowledge. These experiences must be in line with our innate competencies and enhanced by the appropriate opportunities.

# 4

# FROM STEM TO STEAM

## THE PLAYING WITH PROTONS GOES DIGITAL PROPOSED ROADMAP

# 4 FROM STEM TO STEAM: THE PLAYING WITH PROTONS GOES DIGITAL PROPOSED ROADMAP

*“to develop a complex mind, study the science of art, study the art of science, learn how to see.”*

*Leonardo da Vinci*

In this chapter we move towards the integration of the Arts and an enhancer of learning and describe more specifically how this emerged organically during the implementation of Playing With Protons Goes Digital. Arts will act as the backbone for the construction of student’s artifacts and projects. Arts enhanced with technology are the perfect trigger for creativity and critical thinking, eventually leading to a far deeper learning experience for students and teachers. To ensure authenticity in our approach and appropriate justification for implementing the project in schools, we have identified five main categories of commonality between STEM and Art. The five categories are: modes of inquiry; fields of study; experimentation; creativity and imagination; aesthetic experience and artistic attitude. Is there a platform that can incorporate all these characteristics in an integrated activity and still to seem natural even to the young students? In the Playing With Protons Goes Digital approach we are proposing to synchronize STEM and Arts in the school-based activities, using students views and models of the microcosmos as the catalyst in this process and offering a platform to support the visualization of their artifacts. Here we will discuss necessary adjustments in the curricula to allow for such interventions.

## 4.1 MODES OF INQUIRY

Selecting and gathering of information, observing and recording, exploring, investigating and analysing, can all be classified as methods of inquiry common to both science and art. Underpinned by the fundamental need to assimilate, Kemp (2000, pg. 3) says: “Many artists ask ‘why?’ as insistently as any scientist.

For the artist, as for the scientist, every act of looking has the potential to become an act of analysis." Inquiry is fundamental.

Observation, as a method of inquiry requires the ability to see, not only to look. They are not the same. The ability to see requires both the visual awareness and visual literacy skills to focus, identify and cognitively register visual information.

Arnheim (1991, pg. 41) describes artists as "the experts on what you might call the resources of visual language." He speaks of the benefits of such expertise in visual awareness across all disciplines. We would argue, that to possess the capacity of visual literacy when observing and recording and in more abstract imaginings must surely be an elemental faculty of both disciplines, despite its greater emphasis within art education.

According to Bradburne (2002, pg. 9) the skill of careful observation from life has its origins in the Renaissance. He describes Leonardo da Vinci as "the intelligent observer par excellence." Observation from experience at first hand was a key to Leonardo's achievements. He held absolute belief in the necessity for first-hand observation and it fuelled his insatiable desire for the what, how and why of things. The outcome was an unparalleled understanding of the natural world, which informed all his endeavours including his art. For example, as Nicholls (2004, pg. 47) says "detailed botanical knowledge adds a dimension of scientific exactitude to the poetic depiction in his paintings." It illustrates what art educationalists today call 'informed art making.' Contemporary art education would recommend that for a child to draw a tree, it is better for that child to experience the tree, to explore it, discover its qualities using his/her senses and collect information about it. The same approach underpins scientific investigation.

Importantly, in this context Charles Darwin's notebooks contain images, which "are not merely arid records of objective facts useful in inductive reasoning. On the contrary, Darwin's images are full of feeling and show beyond question that when he observed nature, he did so with full range of human emotions" Gruber cited in Caranfa (2001, pg. 155).

When devising the Playing With Protons Goes Digital educational experiences in the form of a long-term program, opportunities for first-hand observation, exploration, analysis etc. have to be provided, including virtual visits to CERN or to other related frontier physics research infrastructures where students have an intro on how scientists explore the microcosmos while at the same time specialist information is provided. Additionally, students will have the chance to perform field trips to national research infrastructures. This is also in keeping with the constructivist view of learning “which acknowledges that children have views and attitudes which are formed as a result of experiences in and out of school and that these must be taken into account if meaningful and transferable learning is to be achieved” Littledyke and Huxford (1998, pg viii).

## 4.2 FIELDS OF STUDY

Even a brief acquaintance with the history of art will inform the viewer that the breadth of study in art is considerable. If we explore the field of contemporary art, the breadth appears to be infinite. Some contemporary artists have helped further scientific investigations. An example being the series of digitally re-mastered photos by Alexa Wright entitled “After Image” which, are the result of working closely with neuro-psychologist Dr. Peter Haligan. Helen Storey (2005) talks of her “passion for science and her hunger to question it through art.” Art has always responded to the breadth of stimulus available at a given time.

In primary schools where teaching occurs through somewhat less complex themes, there exists an abundance of opportunities for collaboration between art and science, providing scope for observation, recording, creativity, imagination, experimentation and so forth. The Playing With Protons Goes Digital implementation has been designed for upper primary school students (ages 10-12). There was an additional reason for this decision. In most educational systems primary school teachers are teaching all subjects (literature science, mathematics). This offers an ideal case for the Playing With Protons Goes Digital intervention as the multidisciplinary character of a large-scale project can be easily achieved. Still the arts lessons are being taught always from an art teacher in the primary school. So, in the Playing With Protons Goes Digital school environments we will have the chance to explore the potential of the cooperation between the teachers focusing on the integration of art in the other subjects of the school curriculum. In the case of Greece, we are planning to expand the implementation to lower secondary level to highlight the challenges and the necessary adaptations.

## 4.3 EXPERIMENTATION

Experimentation or testing, as it is commonly known in science is of primary importance to both disciplines, science and art. This is clear-cut in science, as it obviously provides the necessary data to substantiate a hypothesis, as required, and even emphasised by Leonardo in the 16th century. Perhaps because the 'processes' in art are not so clearly articulated, experimentation is less apparent in this domain. Dewey identified it as an essential requirement of both disciplines and writes with great clarity and insight of the fundamental role of experimentation in art. He speaks of the artist's compulsion "to be an experimenter because he has to express an intensely individualised experience through means and materials that belong to the common and public world" Dewey (1980, pg 144). Each new piece of artwork requires further experimentation, or the artist would simply repeat himself, and become aesthetically dead. Watching even the youngest children involved in art activity, this element is at work in combination with creative thought. Experimentation, problem solving and creativity work in tandem.

During Playing With Protons Goes Digital implementation we will try to offer numerous opportunities for experimentation in both fields. Students will be able to express their creativity and imagination through the design and development of their artifacts, diorama constructions, painting, theatre play, music. Students will be free to choose the way to present their models of microcosmos. The central part for using the experimentation as a catalyst in the science-art interaction is the development of the models of the hydrogen atom or the Sun internal energy production mechanism that must meet specific requirements based on the interaction with scientists in the field.

**Figure 4:** Students will be able to visualize content of complex phenomena describes in their textbooks. A few augmentations will be offered by the project team to help students to get familiarized with the AR platform.

## 4.4 CREATIVITY AND IMAGINATION

Creativity and imagination are unlikely to appear at the forefront of teachers' curricular plans, and their plans for science. Yet it is because of these, connections and comparisons are made, new ideas are born, and information applied. Creativity and imagination are thinking skills that young children possess innately but can fail to be nurtured in the classroom. In the 1970s Bronowski recognised this commonality between art and science and the lack of appreciation for its worth in education. "Science uses images, and experiments with imaginary situations, exactly as art does…to suppose that science does not need imagination, is one of the sad fallacies of our laggard education" Bronowski (1978, pg. 20). Almost thirty years later this respected academic's opinion has had little effect. Murphy and Beggs' (2003, pg. 308) recent research found that science was "frequently taught as facts or as a body of knowledge." There would appear to be an important omission of creativity and imagination in primary curricular science, which needs to be addressed.

While schools may continue to emphasise the acquisition of facts in science, within art creative thinking and imagination are given free reign. Yet they are fundamental to both disciplines. We agree with Eisner who makes the point that both scientists and artists "perceive what is, but imagine what might be, and then use their knowledge, their technical skills, and their sensibilities to pursue what they have imagined" Eisner (2002, pg. 198).

Albert Einstein gives a scientist’s perspective when reflecting on his life as quoted by Clark cited in Gardner (1993, pg. 105) saying “When I examine myself and my methods of thought I come to the conclusion that the gift of fantasy has meant more to me than my talent for absorbing positive knowledge.” He acknowledged that facts have limited value without imagination. Schools should begin to recognise imagination as a prized attribute, and a suitable learning outcome in science as well as art.

The Playing With Protons Goes Digital intervention aims to encourage imagination based on the premise that it is essential in developing the scientific mind. It facilitates this through the subject’s synchronised integration with art. We are inspired by the ways children learn in kindergarten or in the first classes of the primary school: when they create pictures with finger paint, they learn how colours mix together; when they create castles with wooden blocks, they learn about structures and stability. We have tried to extend this early year style of learning, so that students of all ages continue to learn through a creative process of designing, creating, inquiring, experimenting, and exploring. Children have their own way to perceive the Universe surrounding them and their own interpretation of the meaning of life in it. Such endeavours are distinguishing characteristics of an advancing civilization. As people explore, they discover, innovate, prosper, lead— and become great. In Playing With Protons Goes Digital we have selected as the main topic a major challenge for the humankind: The exploration of the secrets of the Universe: The birth and the development of the universe, stars formation and death, our sun, our planetary system, relations with the life on earth. In the framework of Playing With Protons Goes Digital intervention, we offer to our students the opportunity to present their views and their understating by creating models and artifacts. We are offering them the latest technologies to enable them to generate highly imaginative possibilities and to support their deeper learning in STEM.

## 4.5 AESTHETIC EXPERIENCE AND ARTISTIC ATTITUDE

It appears to be widely accepted that facts, reasoning, and analysis belong to the domain of science, while aesthetics and imagination belong to the arts. But this is quite astonishing, for if it were true, what accomplishments would there be in art or science?

For example, renaissance art is underpinned by knowledge of linear and aerial perspective. Without an awareness of colour theory, Romantic, Impressionist and Fauvist painting would not exist. Artists studied and experimented with these concepts and aesthetic experience is made possible in part, due to these scientific accomplishments.

In comparison, if scientists only took rational, fact-based approaches, Albert Einstein would never have been inspired to take leaps of faith, in his exploration of light. To support this view Kemp (2000, pgs. 2-3) says: “At every stage in the process of the undertaking and broadcasting of the most committed kinds of science lie deep structures of intuition which often operate according to what can be described as aesthetic criteria.”

Aesthetic experience is deeply personal. It energises the emotional and cognitive commitment, thus motivating pursuit of further engagement and assimilation. This experience is familiar to those involved in the arts and applicable at all levels of involvement, from preschool to professional career. It relates to joy of engagement as a driving influence. If we consider that aesthetic experience may also be a contributing factor in scientific achievement, then there develops a case for facilitating aesthetic experience in curricular science. Eisner and Powell (2002), following the lead given by Dewey (1934) and supported by Slattery and Langerock (2002, pg. 353) emphasise the need to explore the “personal side of science.”

Aesthetics certainly appear to rest more comfortably in the arts, presumably for their subjective emotional nature, and rationality may have greater prominence in the sciences. But this suggests only single dimensions to what are complex disciplines. When we entertain the idea that art and science are multifaceted, that they have features in common, in recognising this and allowing them each to ‘breath’, then new possibilities arise. Slattery and Langerock citing philosopher Giles Deleuze (2002, pg. 354) state “Through the intertwining of concept and perception, we are able to create and recreate new possibilities and multiplicity of thought.

In Playing With Protons Goes Digital intervention the use of advanced technologies is introduced to enhance the aesthetic experience. Technology also acts as a catalyst in the interaction between science and art. The creations of the students (paintings, models, dioramas and constructions, 3D objects and landscapes, animations, science videos and science theatre plays) are captured according to their projects. The projects will be available on the project’s web platform.

**Figure 5:** By bringing the images of the Sun, the Earth and the Moon, students can visualize the relative motions of these bodies. Such demonstrations will be available to the students during the introductory sessions to help them to get familiarized with the platform.

## 4.6 OVERVIEW

How can it be that societies and their education systems, are so unaware of what makes art and science tick? Initiatives to promote science in schools, have not achieved their goals. Meanwhile the arts have been downgraded in many primary schools. In some cases, functioning as decorative and therapeutic. Bohm argued that, artistic attitude was needed by all, in every phase of life. This chapter has tried to demonstrate that science and art do share common features, which it has been difficult to do justice to in these few words. With subject integration being promoted in 21st century education, it would be careless to overlook the commonalities between art and science or fail to recognise that therein, may lie pedagogical gains for students. In the Playing With Protons

Goes Digital project the five commonalities described above are acting as catalysts in the integration of science and art in the learning experience of the students. They provide substantial justification for devising and testing our integrated large-scale project. The Playing With Protons Goes Digital proposed activities fully maintains the integrity of both subjects, which tends to be a problem in cross-curricular and thematic approaches. It also promotes aspects of both subjects which are sometimes neglected such as creative thinking in science and informed art making.

# 5

# CONCLUSIONS

# 5 CONCLUSIONS

This document describes the Conceptual and Methodological Framework of the project. It highlights the a) the Deeper Learning Competence Framework which describes the learners deep learning profiles and provides a series of requirements that the project team must meet to create the necessary opportunities for learners to experience the deeper learning proficiency levels and b) the Roadmap from STEM to STEAM that identifies the essential Features of Creative Science Education. Based on these we are proposing a structured template to guide teachers and students during the design and development of their projects and artifacts. The document presents the added value of the Innovative Curricula for 21st Century Learners: From Small to Big Ideas of Science which describe the overall effort and provide the necessary recommendations for future actions and for policy makers and curricula developers.

This document describes the Playing With Protons Goes Digital Deeper Learning Paradigm and presents also the main challenges for the project to create the necessary opportunities for learners' Deeper Learning. It also describes the Deeper Learning Competencies and the essential abilities which are the main reference for the development of learners' Deeper Learning Profiles. This is the first step towards a major challenge that this project has set to meet: The development and application of technology-based assessment instruments that allow to universally assess all essential abilities that are central to deeper learning. The assessment data (performance indicators) generated by these tools can be utilized for populating and updating the participating learners' Deeper Learning competence profiles. This kind of overview can support Educators' evidence-based coaching, teaching planning and/or classroom delivery. Playing With Protons Goes Digital pedagogical framework promotes the idea of Educators' professional wisdom. This document forms the basis for the development of a series of methods and tools for assessing Deeper Learning in STEM in the framework of the Playing With Protons Goes Digital project. Based on the Playing With Protons Goes Digital Deeper Learning Paradigm, the assessment has to address all six deeper learning competencies (along with the partial abilities in each case) that can be divided into the two ability domains (i.e., intellectual and motivational abilities). It explains the selection of the main intervention method in the project. The study of the universe and the microcosmos offers unique opportunities for the evaluation team to assess the full set of competences that are forming the deeper learning paradigm. We will have the chance to monitor numerous students' activities during the creation of their artifacts, during the development of their projects and during the presentations and the discussion that will take place. It presents a series of methods and instruments to assess the deeper learning competencies. Based on existing STEM knowledge scales for learners' specific questions relating to the content of the Playing With Protons Goes Digital must be developed together with the intervention designers.

Annex 2 could act as an initial template for the design of the Playing With Protons Goes Digital activities providing the necessary guidance to the school communities, to the technical team who will develop the necessary tools for creation of the learners' projects and the research team who will have a reference for the assessment of the deeper learning competencies that the learners are expected to develop during their involvement in the Playing With Protons Goes Digital activities.

This document must be used in parallel O2 that describes a number of proposed activities for the classroom. These activities will be used as reference points for the project implementation in the school environments. This document includes numerous references which can be used for further reading in the field.

# 6

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# 6 REFERENCES


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# 7

## ANNEX 1

# DESCRIBING PROGRESSION TOWARDS THE BIG IDEAS

# 7 ANNEX 1: DESCRIBING PROGRESSION TOWARDS THE BIG IDEAS

According to the Big Ideas approach (Based on the document Working with Big Ideas of Science Education, edited by Wynne Harlen in 2015)[1] the aim is to provide a description – a narrative – of how ideas change from the small ideas, to the big ones presented in Chapter 3.

The narrative fills in some ideas that are formed in the progress from the beginning ideas to the broad, more abstract ideas that enable understanding of objects, phenomena and relationships in the natural world (ideas 1-10).

We provide the same kind of description of how these understandings are achieved, that is, ideas about science (ideas 11-14). Under each heading, where applicable, we begin with the small and contextualized ideas that students in the primary or elementary school, through appropriate activities and with support, will be able to grasp. These are followed by ideas that lower secondary school students can develop as their increasing capacity for abstract thinking enables them to see connection between events or phenomena.

As exploration of the natural world extends in later secondary education, continuation of this creation of patterns and links enables students to understand relationships and models that can be used in making sense of a wide range of new and previous experiences.

A side bar is used to indicate the general range of ideas appropriate for different stages of schooling. As there is so much variety in the way that phases of education are described in different countries, we have labelled them in terms of ages, but using deliberately overlapping ranges since we do not intend to identify hard boundaries between what is appropriate at various ages. It is

1 https://www.interacademies.org/26703/Working-with-Big-Ideas-of-Science-Education

important to allow for diversity in the paths of cognitive development of individual students.

What is important is the general direction of progress towards useful explanatory frameworks built on sound understanding at each stage. The ideas developed at all stages should be seen as contributing to this ongoing development. At each stage the aim is to move a little further towards a big idea, not to try to forge a link between every activity and the most sophisticated form of the idea. How far students can move in this direction at any time depends on several contextual variables, not least the pedagogy they experience.

# 1 All matter in the Universe is made of very small particles

*Atoms are the building blocks of all matter, living and non-living. The behaviour and arrangement of the atoms explains the properties of different materials. In chemical reactions, atoms are rearranged to form new substances. Each atom has a nucleus containing neutrons and protons, surrounded by electrons. The opposite electric charges of protons and electrons attract each other, keeping atoms together and accounting for the formation of some compounds.*

5-7

All the 'stuff' encountered in everyday life, including air, water and different kinds of solid substances, is called matter because it has mass, and therefore weight on Earth, and takes up space. Different materials are recognisable by their properties, some of which are used to classify them as being in the solid, liquid or gas state.

7-11

When some substances are combined they form a new substance (or substances) with properties that are different from the original ones. Other substance simply mix without changing permanently and can often be separated again. At room temperature, some substances are in the solid state, some in the liquid state and some in the gas state. The state of many substances can be changed by heating or cooling them. The amount of matter does not change when a solid melts or a liquid evaporates.

11-14

If a substance could be divided into smaller and smaller pieces it would be found to be made of very, very small particles, smaller than can be seen even with a microscope. These particles are not in a substance; they are the substance. All the particles of a particular substance are the same and different from those of other substances. The particles are not static but move in random directions. The speed at which they move is experienced as the temperature of the material. The differences between substances in the solid, liquid or gas state can be explained in terms of the speed and range of the movement of particles and the separation and strength of the attraction between neighbouring particles. The stronger the force of attraction between the particles the more energy has to be transferred to the substance to separate the particles , for example in going from the solid to the liquid state or from the liquid to the gas state. This is why substances have different melting and boiling points.

All materials, anywhere in the universe, living and non-living, are made of a very large numbers of basic 'building blocks' called atoms, of which there are about 100 different kinds. Substances made of only one kind of atom are called elements. Atoms of different elements can combine together to form a very large number of compounds. A chemical reaction involves a rearrangement of the atoms in the reacting substances to form new substances, while the total amount of matter remains the same. The properties of different materials can be explained in terms of the behaviour of the atoms and groups of atoms of which they are made.

14-17

Atoms themselves have an internal structure, consisting of a heavy nucleus, made of protons and neutrons, surrounded by light electrons. The electrons and protons have electric charge – that of an electron being called negative and that of a proton called positive. Atoms are neutral, charges balancing exactly. Electrons move rapidly in matter, forming electric currents and causing magnetic forces. Their net effect is a force of attraction holding atoms and molecules together in compounds. When some electrons are removed or added, the atoms are left with a positive or negative charge and are called ions.

In some atoms the nucleus is unstable and may emit a particle, a process called radioactivity. This process involves the release of radiation and an amount of energy far greater than any reaction between atoms. The behaviour of matter at the scale of nuclei, atoms and molecules is different from that observed at the scale of ordinary experience.

# 2 Objects can affect other objects at a distance

*All objects have an effect on other objects without being in contact with them. In some cases the effect travels out from the source to the receiver in the form of radiation (e.g. visible light). In other cases action at a distance is explained in terms of the existence of a field of influence, such as a magnetic, electric or gravitational field. Gravity is a universal attraction between all objects however large or small, keeping the planets in orbit round the Sun and causing terrestrial objects to fall towards the centre of the Earth.*

7-11

Objects can have an effect on other objects even when they are not in contact with them. For instance, light, both from close sources such as light bulbs or flames and from the Sun and other stars very long distances away, is seen because it affects the objects it reaches, including our eyes. These sources give out light, which travels from them in various directions and is detected when it reaches and enters our eyes. Objects that are seen either give out or reflect light that human eyes can detect. Sound comes from things that vibrate and can be detected at a distance from the source because the air or other material around is made to vibrate. Sounds are heard when the vibrations in the air enter our ears. Other examples of objects affecting other objects without touching them are the interactions between magnets or electric charges and the effect of gravity that makes things falls to the Earth.

11-14

Gravity is the universal attraction between all objects, however large or small, although it is only apparent when one of the objects is very large. This gravitational attraction keeps the planets in orbit round the Sun, the Moon round the Earth and their moons round other planets. On the Earth it results in everything being pulled down towards the centre of the Earth. We call this downward attraction the weight of an object. The object pulls the Earth as much as the Earth pulls the object, but because the Earth's mass is much bigger, we observe the resulting motion of the object, not of the Earth. The effect of gravity on an object on the Moon is less than that on Earth because the Moon has less mass than the Earth, so a person on the Moon weighs less than on Earth even though their mass is the same. The pull of the Earth on the Moon keeps it orbiting the Earth while the pull of the Moon on the Earth gives rise to tides.

14-17

Visible light is one example of radiation, which spreads out in a way resembling how waves spread across water. Other kinds of radiation are not visible to the human eye and include radio waves, microwaves, infra-red, ultra-violet, X rays and gamma radiation, which differ from each other in wavelength. These can all travel through empty space (vacuum). Thinking of radiation as waves can help to explain how it behaves. Although sound spreads out like waves it cannot travel through empty space; there has to be some continuous material, in a solid, liquid or gas state, between the source and the receiver for the vibrations to travel through.

When radiation hits another object, it may be reflected, absorbed or scattered by it, pass through it, or a combination of these. When reflected by a mirror or transmitted through a transparent material, the radiation remains the same, but when it is absorbed in an object it changes and causes a rise in temperature of the object.

Some cases of action at a distance are not explained in terms of radiation from a source to a receiver. A magnet, for example, can attract or repel another magnet and both play equal parts. Similarly, the attraction and repulsion between electric charges is reciprocal. The idea of a field is useful for thinking about such situations. A field is the region of the object's influence around it, the strength of the field decreasing with distance from the object. Another object entering this field experiences an effect – attraction or repulsion. Gravity, electric and magnetic interactions can be described in terms of fields.

# 3 Changing the movement of an object requires a net force to be acting on it

*A force acting on an object is not perceived directly but is detected by its effect on the object's motion or shape. If an object is not moving the forces acting on it are equal in size and opposite in direction, balancing each other. Since gravity affects all objects on Earth there is always another force opposing gravity when an object is at rest. Unbalanced forces cause change in movement in the direction of the net force. When opposing forces acting on an object are not in the same line they cause the object to turn or twist. This effect is used in some simple machines.*

5-7

Forces can push, pull or twist objects, making them change their motion or shape. Forces act in particular directions. Equal forces acting in opposite directions in the same line cancel each other and are described as being in balance. The movement of objects is changed if the forces acting on them are not in balance.

7-11

The speed of a moving object is a measure of how far it would travel in a certain time. How quickly an object's motion is changed depends on the force acting and the object's mass. The greater the mass of an object, the longer it takes to speed it up or slow it down, a property of mass described as inertia.

11-14

All objects on the Earth are affected by gravitational forces. An object which stays at rest on the surface of the Earth has one or more forces acting on it counter balancing the force of gravity. A book lying on a table does not fall because the atoms in the table are pushing upwards on the book with a force equal to the downward force of gravity. An object floating in a liquid or in air does not move because there is an upward force balancing the downward force of gravity. The upward force is equal to the weight of the fluid displaced so heavy objects can float if they are hollowed out to displace a large weight of water.

14-17

When forces acting on an object are not equal and opposite in direction, their resulting effect is to change the object's motion, to speed it up (acceleration) or slow it down (deceleration). Often the force that is acting is not recognised as a force and a moving object, such as a rolling ball, is assumed to slow down automatically. In fact its motion is gradually being slowed by the force of friction with its surroundings. In all cases change in motion is caused by unbalanced forces. If no net force is acting any motion will not change; the object will remain stationary or, if in motion, go on forever in a straight line. Change in motion is in the direction of the net force; motion at right angles is not affected. Satellites stay in orbit round the Earth because they are sent off with enough force to reach a height where their motion is in a curved orbit around the Earth due to the force of gravity constantly changing the direction of motion and there is no air resistance to slow them down.

When opposing forces acting on a solid object are not in the same line, they act to turn or twist the object. The turning effect of a force depends on its distance from the axis about which it turns. The further the distance from the turning point the less force is needed but the further it has to move. This has many applications in tools and machines where a small force acting over a large distance is used to produce a large force acting over a small distance.

Pressure is a measure of the amount of force acting on a particular area. A force spread over a larger area produces less pressure than when spread over a smaller area, a relationship with many applications, from snow shoes to drawing pins. The pressure in a fluid (liquid or gas) at particular point depends on the weight of fluid above that point, so air pressure on Earth decreases with increasing height above the ground and pressure in a liquid increases with depth.

# 4 The total amount of energy in the Universe is always the same but can transferred from one energy store to another during an event

*Many processes or events involve changes and require an energy source to make them happen. Energy can be transferred from one body or group of bodies to another in various ways. In these processes some energy becomes less easy to use. Energy cannot be created or destroyed. Once energy has been released by burning a fossil fuel with oxygen, some of it is no longer in a form that is as convenient to use.*

5-7

There are various ways of causing an event or bringing about change in objects or materials. Objects can be made to change their movement by pushing or pulling. Heating can cause change, as in cooking, melting solids or changing water to vapour. Electricity can make light bulbs glow. Wind can rotate the blades of wind turbines.

7-11

In all these changes, energy is transferred from one object, which is an energy source or resource, to another. Fuels such as oil, gas, coal and wood are energy resources. Some energy resources are renewable, such as those produced by wind, waves, sunlight and tides, others are non-renewable such as from burning fossil fuels with oxygen.

11-14

Objects can have stored energy (that is, the ability to make things change) either because of their chemical composition (as in fuels and batteries), their movement, their temperature, their position in a gravitational or other field, or because of compression or distortion of an elastic material. Energy can be stored by lifting an object higher above the ground. When it is released and falls, this energy is stored in its motion. When an object is heated it has more energy than when it is cold. An object at a higher temperature heats the surroundings or cooler objects in contact with it until they are all at the same temperature. How quickly this happens depends on the kind of material which is heated and on the materials between them (the extent to which they are thermal insulators or conductors). The chemicals in the cells of a battery store energy which is released when the battery is connected so that an electric current flows, transferring energy to other components in the circuit and on to the environment. Energy can be transferred by radiation, as sound in air or light in air or a vacuum.

Many processes and phenomena are described in terms of energy exchanges, from the growth of plants to the weather. The transfer of energy in making things happen almost always results in some energy being shared more widely, heating more atoms and molecules and spreading out by conduction or radiation. The process cannot be reversed and the energy of the random movement of particles cannot as easily be used. Thus some energy is dissipated.

14-17

Energy cannot be created or destroyed. When energy is transferred from one object to others the total amount of energy in the universe remains the same; the amount that one object loses is the same as the other objects gain. When the Sun heats the Earth, the Sun is gradually losing energy through radiation, heating the Earth and other planets. The mass of atoms is a form of stored energy, called nuclear energy. Radioactive atoms release this energy which may become available as heat.

Across the world, the demand for energy increases as human populations grow and because modern lifestyles require more energy, particularly in the convenient form of electrical energy. Fossil fuels, frequently used in power stations and generators, are a limited resource and their combustion contributes to global warming and climate change. Therefore other ways of generating electricity have to be sought, whilst reducing demand and improving the efficiency of the processes in which we use it.

# 5 The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate

*Radiation from the Sun heats the Earth's surface and causes convection currents in the air and oceans, creating climates. Below the surface heat from the Earth's interior causes movement in the molten rock. This in turn leads to movement in the plates which form the Earth's crust, creating volcanoes and earthquakes. The solid surface is constantly changing through the formation and weathering of rock.*

5-7

7-11

There is air all around the Earth's surface but there is less and less further away from the surface (higher in the sky). Weather is determined by the conditions and movement of the air. The temperature, pressure, direction, speed of movement and the amount of water vapour in the air combine to create the weather. Measuring these properties over time enables patterns to be found that can be used to predict the weather a short time ahead. Long-term patterns in the weather are referred to as the climate of different parts of the world.

Much of the solid surface of the Earth is covered by soil, which is a mixture of pieces of rock of various sizes and the remains of organisms. Fertile soil also contains air, water, some chemicals from the decay of living things, particularly plants, and various living things such as insects, worms and bacteria. The solid material beneath the soil is rock. There are many different kinds of rock with different compositions and properties. The action of wind and water wears down rock gradually into smaller pieces – sand is made of small pieces of rock and silt of still smaller pieces. About two-thirds of the surface of the Earth is covered by liquid water, which is essential to life. Water is constantly recycled through processes involving evaporation from oceans and other surfaces, such as soil and plants, condensation in clouds and precipitation as rain, snow or hail.

11-14

The layer of air at the Earth's surface is transparent to most of the radiation coming from the Sun, which passes through. The radiation that is absorbed at its surface is the Earth's external source of energy. Radioactive decay of material inside the Earth since it was formed is its internal source of energy. Radiation from the Sun provides the energy that enables plants containing chlorophyll to make glucose through the process of photosynthesis. The radiation from the Sun absorbed by the Earth warms the surface which then emits radiation of longer wavelength (infra-red) that does not pass through the atmosphere but is absorbed by it, keeping the Earth warm. This is called the greenhouse effect because it is similar to the way the inside of a greenhouse is heated by the Sun.

14-17

Oxygen in the atmosphere, produced by plants during photosynthesis, indirectly protects the Earth from the short wave (ultra-violet) part of the Sun's radiation which is harmful to many organisms. The action of ultra-violet radiation on oxygen in the upper atmosphere produces ozone which absorbs this harmful radiation. The temperature at the Earth's surface results from a delicate balance, which can be upset by adding gases to the atmosphere. Human activities produce carbon dioxide and methane which increase the greenhouse effect and leads to global warming and climate change.

Beneath the Earth's solid crust is a hot layer called the mantle. The mantle is solid when under pressure but melts (and is called magma) when the pressure is reduced. In some places there are cracks (or thin regions) in the crust which can allow magma to come to the surface, for example in volcanic eruptions. The Earth's crust consists of a number of solid plates which move relative to each other, carried along by movements of the mantle. Where plates collide, mountain ranges are formed and there is a fault line along the plate boundary where earthquakes are likely to occur and there may also be volcanic activity. The Earth's surface changes slowly over time, with mountains being eroded by weather, and new ones produced when the crust is forced upwards.

# 6 Our solar system is a very small part of one of billions of galaxies in the Universe

*Our Sun and eight planets and other smaller objects orbiting it comprise the solar system. Day and night and the seasons are explained by the orientation and rotation of the Earth as it moves round the Sun. The solar system is part of a galaxy of stars, gas and dust, one of many billions in the Universe, enormous distances apart. Many stars appear to have planets.*

5-7

There are patterns in the position of the Sun seen at different times of the day and in the shape of the Moon from one night to another.

7-11

The Earth moves round the Sun taking about a year for one orbit. The Moon orbits the Earth taking about four weeks to complete an orbit. The Sun, at the centre of the solar system, is the only object in the solar system that is a source of visible light. The Moon reflects light from the Sun and as it moves round the Earth only those parts illuminated by the Sun are seen. The Earth rotates about an axis lying north to south and this motion makes it appear that the Sun, Moon and stars are moving round the Earth. This rotation causes day and night as parts of the Earth's surface turn to face towards or away from the Sun. It takes a year for the Earth to pass round the Sun. The Earth's axis is tilted relative to the plane of its orbit round the Sun so that the length of day varies with position on the Earth's surface and time of the year, giving rise to the seasons.

11-14

The Earth is one of eight (so far known) planets in our solar system which, along with many other smaller bodies, orbit the Sun, in roughly circular paths, at different distances from the Sun and taking different times to complete an orbit. The distances between these bodies are huge – Neptune is 4.5 billion km from the Sun, 30 times further than Earth. As seen from Earth, planets move in relation to the positions of the stars which appear fixed relative to each other. Exploring the solar system is possible with robotic missions, or by humans at shorter distances from the Earth.

14-17

Occasionally a large chunk of rock orbiting the Sun gets close enough to the Earth to be pulled into its gravitational field and accelerates through the atmosphere where friction between the air and the surface of the rock causes it to heat up and glow, when it can be seen as a 'shooting star'. A meteor is a rock that is all burnt up on entering the atmosphere but if some of it reaches the Earth's surface it becomes a meteorite. Otherwise movements of object within the solar system are mostly regular and predictable. The same scientific laws – generalisations about how things behave – that apply on Earth also apply throughout the Universe. There is evidence from space exploration that changes have taken place on the surface of the planets since they were formed. Life has not (yet) been discovered anywhere outside Earth.

Our Sun is one of many stars that make up the Universe, essentially made of hydrogen. The source of energy that the Sun and all stars radiate comes from nuclear reactions in their central cores. The Sun is one of millions of stars that together make up a galaxy called the Milky Way. The next nearest star is much further away than the distance of the furthest planet, Neptune. The distances between and within galaxies are so great that they are measured in 'light years', the distance that light can travel in a year. There are billions of galaxies in the universe, almost unimaginably vast distances apart and perceived as moving rapidly away from each other. This apparent movement of galaxies indicates that the Universe is expanding from an event called a 'big bang', about 13.7 billion years ago.

# 7 Organisms are organised on a cellular basis and have a finite life span

*All organisms are constituted of one or more cells. Multi-cellular organisms have cells that are differentiated according to their function. All the basic functions of life are the result of what happens inside the cells which make up an organism. Growth is the result of multiple cell divisions.*

5-7

7-11

There is a wide variety of living things (organisms), including plants and animals. They are distinguished from non-living things by their ability to move, reproduce and react to certain stimuli. To survive they need water, air, food, a way of getting rid of waste and an environment which stays within a particular range of temperature. Although some do not appear to be active, all will at some stage carry out the life processes of respiration, reproduction, feeding, excretion, growth and developments and all will eventually die.

11-14

All living organisms are made of one or more cells, which can be seen only through a microscope. All the basic processes of life are the results of what happens inside cells. Cells divide to replace aging cells and to make more cells in growth and in reproduction. Food is the energy source they need in order to carry out these and other functions. Some cells in multi-cellular organisms, as well as carrying out the functions that all cells do, are specialised; for example, muscle, blood and nerve cells carry out specific functions within the organism.

Cells are often aggregated into tissues, tissues into organs, and organs into organ systems. In the human body, systems carry out such key functions as respiration, digestion, elimination of waste and temperature control. The circulatory system takes material needed by cells to all parts of the body and removes soluble waste to the urinary system. Stem cells, which are not specialised, are capable of repairing tissues by being programmed for different functions. Cells function best in certain conditions. Both single cell and multi-cellular organisms have mechanisms to maintain temperature and acidity within certain limits that enable the organism to survive.

14-17

Within cells there are many molecules of different kinds which interact in carrying out the functions of the cell. In multi-cellular organisms cells communicate with each other by passing substances to nearby cells to coordinate activity. A membrane around each cell plays an important part in regulating what can enter or leave a cell. Activity within different types of cell is regulated by enzymes. Hormones, released by specialised tissues and organs, regulate activity in other organs and tissues and affect the overall functioning of the organism. In humans, most hormones are transported in the blood. Many medicines operate by speeding up or slowing down the regulatory mechanisms of enzymes or hormones. The brain and spinal cord also contribute to the regulation of cell activity, by sending messages along nerve cells in the form of electrical signals, which travel quickly between cells.

Given a suitable medium, cells from a variety of organisms can be grown *in situ*, that is, outside the organism. These cell cultures are used by scientists to investigate cell functions, and have medical implications such as the production of vaccines, screening of drugs, and in vitro fertilisation. Plant tissue culture is used widely in the plant sciences, forestry, and in horticulture.

Most cells are programmed for a limited number of cell divisions. Diseases, which may be caused by invading microorganisms, environmental conditions or defective cell programming, generally result in disturbed cell function. Organisms die if their cells are incapable of further division.

# 8 Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms

*Food provides materials and energy for organisms to carry out the basic functions of life and to grow. Green plants and some bacteria are able to use energy from the Sun to generate complex food molecules. Animals obtain energy by breaking down complex food molecules and are ultimately dependent on green plants as their source of energy. In any ecosystem there is competition among species for the energy resources and the materials they need to live and reproduce.*

5-7

All living things need food as their source of energy as well as air, water and certain temperature conditions. Plants containing chlorophyll can use sunlight to make the food they need and can store food that they do not immediately use. Animals need food that they can break down, which comes either directly by eating plants (herbivores) or by eating animals (carnivores) which have eaten plants or other animals. Animals are ultimately dependent on plants for their survival. The relationships among organisms can be represented as food chains and food webs.

7-11

Some animals are dependent on plants in other ways as well as for food, for example for shelter and, in the case of human beings, for clothing and fuel. Plants also depend on animals in various ways. For example, many flowering plants depend on insects for pollination and on other animals for dispersing their seeds.

11-14

Interdependent organisms living together in particular environmental conditions form an ecosystem. In a stable ecosystem there are producers of food (plants), consumers (animals) and decomposers, (bacteria and fungi which feed on waste products and dead organisms). The decomposers produce materials that help plants to grow, so the molecules in the organisms are constantly re-used. At the same time, energy resources pass through the ecosystem. When food is used by organisms for life processes some energy is dissipated as heat but is replaced in the ecosystem by radiation from the Sun being used to produce plant food.

In any given ecosystem there is competition among species for the energy resources and the materials they need to live. The persistence of an ecosystem depends on the continued availability in the environment of these energy resources and materials. Plant species have adaptations to obtain the water, light, minerals and space they need to grow and reproduce in particular locations characterised by climatic, geological and hydrological conditions. If conditions change, the plant populations may change, resulting in changes to animal populations.

14-17

Human activity which controls the growth of certain plants and animals changes an ecosystem. Forestry which favours the growth of certain trees over others removes the food plants of certain animals and so reduces the diversity of species dependent on these plants and of other organisms in the food chain. Modern farming is designed to reduce biodiversity by creating conditions that are suited to particular animals and plants in order to feed the human population. The widespread use of pesticides to preserve one type of crop has widespread effects on pollinating insects on which many other plants depend. Human activity of this kind creates a simple and unnatural ecosystem which limits biodiversity and results in the loss of culturally valuable landscape and wildlife.

# 9 Genetic information is passed down from one generation of organisms to another

*Genetic information in a cell is held in the chemical DNA. Genes determine the development and structure of organisms. In asexual reproduction all the genes in the offspring come from one parent. In sexual reproduction half of the genes come from each parent.*

5-7

7-11

Living things produce offspring of the same kind, but offspring are not identical with each other or with their parents. Plants and animals, including humans, resemble their parents in many features because information is passed from one generation to the next. Other features, such as skills and behaviour, are not passed on in the same way and have to be learned.

11-14

Inside the nucleus of animal and plant cells are structures called chromosomes which hold large complex molecules of DNA. When cells divide the information that is needed to make more cells is in the form of a code represented in the way that the parts of the DNA molecule are put together. A gene is a length of DNA; and hundreds or thousands of genes are carried on a single chromosome. In the human body most cells contain 23 pairs of chromosomes with a total of about twenty thousand genes.

When a cell divides, as in the process of growth or replacement of dead cells, genetic information is copied so that each new cell carries a replica of the parent cell. Sometimes an error occurs in replication, causing a mutation, which may or may not be damaging to the organism. Changes in genes can be caused by environmental conditions, such as radiation and chemicals. These changes can affect the individual but only affect the offspring if they occur in sperm or egg cells.

In sexual reproduction, a sperm cell from a male unites with an egg cell from a female. Sperm and egg cells are specialised cells each of which has one of the two versions of each gene carried by the parent, selected at random. When a sperm and egg combine half the genetic material in the fertilised egg is from the sperm cell and half from the egg cell. As the fertilised egg divides time and time again this genetic material is duplicated in each new cell. The sorting and recombining of genetic material when egg and sperm cells are formed and then fuse results in an immense variety of possible combinations of genes, and in differences that can be inherited from one generation to another. These provide the potential for natural selection as a result of some variations making organisms better adapted to certain environmental conditions.

14-17

Asexual reproduction, which occurs naturally in a wide range of organisms including some bacteria, insects and plants, leads to populations with identical genetic material. Biotechnology has made possible the production of genetically identical organisms through artificial cloning in a range of species including mammals.

The overall sequence of genes of an organism is known as its genome. More is being learned all the time about genetic information by mapping the genomes of different kinds of organisms. When sequences of genes are known genetic material can be artificially changed to give organisms certain features. In gene therapy special techniques are used to deliver into human cells genes that are beginning to help in curing disease.

# 10 The diversity of organisms, living and extinct, is the result of evolution

*All life today is directly descended from a universal common ancestor that was a simple one-celled organism. Over countless generations changes resulting from natural diversity within a species lead to the selection of those individuals best suited to survive under certain conditions. Species not able to respond sufficiently to changes in their environment become extinct.*

5-7

7-11

There are many different kinds of plants and animals in the world today and many kinds that once lived but are now extinct. We know about these from fossils. Animals and plants are classified into groups and subgroups according to their similarities. For example within the group of animals called birds, there are families of birds such as sparrow, and different kinds (species) within a family such as house sparrows, tree sparrows, and great sparrows. Organisms of the same species breed more of the same. Different species cannot interbreed to produce offspring that can reproduce. Although organisms of the same species are very similar they vary a little from each other. One of the results of sexual reproduction is that offspring are never exactly like their parents.

11-14

Living things are found in certain environments because they have features that enable them to survive there. This adaptation to their environment has come about because of the small differences that occur during reproduction, resulting in some individuals being better suited to the environment than others. In the competition for materials and energy resources, those that are better adapted are more likely to survive and may pass on their adapted feature to their offspring. Those less suited to a particular environment are more likely to die before reproducing, so later generations will contain more of the better adapted individuals. This only applies to changes (mutations) in the reproductive cells; mutations in other cells are not passed on. Over time, these changes can accumulate to the point where the survivors have become a different species.

The natural selection of organisms with certain features that enable them to survive in particular environmental conditions has been going since the first form of life appeared on Earth about 3.5 billion years ago. Simple single-celled organisms arose early in the history of life. About two billion years ago some of these evolved into multi-cellular organisms that eventually gave rise to today's large animals, plants and fungi. Other forms remained unicellular.

14-17

When climatic, geological or population changes occur, the benefit of particular inherited features may be enhanced or diminished. The process of adaptation that occurs naturally and very slowly is speeded up by human intervention through the selection for breeding those animals or plants with the features that suit them for particular functions or environments.

Human activity can change the environment more quickly than organisms can respond through adaptation. Water, air and soil pollution as well as intensive farming can impose far-reaching effects on the environment and has already resulted in changes that are damaging to many organisms. The present rate of extinction as a result of human activities is hundreds of times what is would be if there were no people. A reduction in the diversity of life can lead to significant ecosystem degradation and loss of ability to respond to changes in the environment.

Evolution of life on Earth is only a limited aspect of what is called 'cosmic evolution'. This refers to the gradual changes in the physical and chemical conditions of the galaxies, such as the appearance of the carbon atom, which has led to favourable conditions for the existence of life, at least on Earth.

# 11 Science is about finding the cause or causes of phenomena in the natural world

*Science is a search to explain and understand phenomena in the natural world. There is no single scientific method for doing this; the diversity of natural phenomena requires a diversity of methods and instruments to generate and test scientific explanations. Often an explanation is in terms of the factors that have to be present for an event to take place as shown by evidence from observations and experiments. In other cases supporting evidence is based on correlations revealed by patterns in systematic observation.*

7-11

Science is about finding explanations for why things happen as they do or why they take a particular form, assuming that every event or phenomenon has a cause or causes and that there is a reason for the form things take. An explanation is not a guess; there has to be some basis for it. There are various ways of finding out what makes things work or why they happen. Careful observation, including measurement where possible, can suggest what may be happening. In other cases it is possible to do something to make a change and observe what happens. When this is done it is important to see that other things stay the same so that the result can only be the effect of changing one thing.

11-14

Careful and systematic observations and accurate descriptions of what is observed are fundamental to scientific investigation. What people expect to happen can influence what they observe, so it is good practice for observations to be made by several people independently and for results to be reported clearly enough to be checked by others.

Different kinds of natural phenomena are explained in different ways. In some cases a possible explanation (hypothesis) indicates the variable factor thought to cause a phenomenon. To test a hypothesis it is used to predict what will happen when the variable identified as a possible cause is changed and then see if what happens fits the prediction. If the outcome agrees with the prediction, and no other changes are found to produce the same result, then the factor is accepted as being the cause that explains the observation.

14-17

Where factors cannot be experimentally manipulated, as in the case of the movement of planets in the solar system, a phenomenon can be investigated by observing systematically on several occasions and over a period of time. Looking for patterns in the data may reveal that there is a correlation between factors – as one factor changes, so does another in a regular way. A correlation may be used to propose a hypothesis, which can be used to make predictions, even though it may involve aspects that cannot be directly observed or changed. However, a correlation cannot usually be taken as conclusive evidence that change in one factor is the cause of the change in the other because there could be some other factor (so far unidentified) that is causing both. Finding that one thing is the cause of an effect is not the same as explaining the mechanism by which the effect is brought about. For that, a model of the relationships based on scientific principles is needed.

Phenomena that occurred in the past, such as rock changes or species evolution, can also be submitted to the process of hypothesis testing. In such cases, it is the coherence of all hypotheses consistent with all known facts and scientific principles which provides the best possible explanation.

# 12 Scientific explanations, theories and models are those that best fit the evidence available at a particular time

*A scientific theory or model representing relationships between variables of a natural phenomenon must fit the observations available at the time and lead to predictions that can be tested. Any theory or model is provisional and subject to revision in the light of new data even though it may have led to predictions in accord with data in the past.*

**5-7**

Everyone can ask questions about things in the natural world and can do something to find answers that help explain what is happening.

**7-11**

In science explanations are sought through some kind of systematic inquiry that involves collecting data by observing or measuring features of the objects being studied or using data from other sources. Whether or not an effective explanation can be obtained depends on what data are collected and this is usually guided by having some theory or hypothesis about what might be happening.

**11-14**

To help in the process of explaining observations and what makes things happen, scientists create models to represent what they think may be happening. Sometimes these are physical models, such as an orrery – a model of the solar system where various objects are used to represent the Sun, Moon, Earth and other planets – or a ball and stick model of how atoms are thought to be arranged in a substance. Other models are theoretical, more abstract, such as in representing light as a wave motion, or representing relationships as mathematical formulae. Computer-based models enable phenomena to be simulated and variables easily changed to investigate their effect. Some models are firmly established in theories which have been shown to work without contradiction in all contexts so far encountered. Others are more tentative and are likely to be changed in future. There may be more than one possible model and the evidence of which works best is not conclusive; and in other cases we do not yet have a satisfactory explanatory model.

**14-17**

Models provide ways of explaining phenomena in terms of relationships between parts of a system. They are developed through an iterative process of comparing what they predict with what is found in the real world. Model-based reasoning goes beyond what can be observed directly, whilst keeping the link with evidence by comparing what a model predicts with what can be observed.

Scientific explanations account for specific events or phenomena in terms of a theory or model. Explanations do not emerge self-evidently from data but are created in a process that often involves intuition, imagination and informed hypothesis. A scientific theory is a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and so become well established.

If new data do not fit current ideas then the ideas have to be changed or replaced by alternative ideas. Although there is greater confidence in ideas or models that leads to predictions that are repeatedly and reliably confirmed by evidence – and so become regarded as facts – an explanation or theory can never be proved 'correct' because there is always the possibility of further data conflicting with it or because a new theory is found that also provides a good explanation. So some scientific ideas used today to explain things around us are different from the ones accepted in the past and some may well be different in the future.

# 13 The knowledge produced by science is used in engineering and technologies to create products

*The use of scientific ideas in technologies has made considerable changes in many aspects of human activity. Advances in technologies enable further scientific activity; in turn this increases understanding of the natural world. In some areas of human activity technology is ahead of scientific ideas, but in others scientific ideas precede technology.*

5-7

Technologies have been created by people to provide the things they need or can use, such as food, tools, clothes, somewhere to live and ways of communicating. All around us are examples of how materials have been changed so that they can be used for certain purposes.

7-11

Technologies are developed using engineering, which involves identifying problems and using ideas of science and other ideas to design and develop the best possible solution. There are always different ways of approaching problems, so various possibilities need to be tried out. In order to decide which is the best solution it is necessary to be clear about what the result is intended to be and so how success is to be judged. For instance, a solution to the problem of being able to see the back of your head would be different if a criterion for success is to leave your hands free.

11-14

Designing a solution to a problem generally involves making a drawing or model. Physical, mathematical or computer models enable the effect of changes in materials or design to be tested and the solution improved. There are usually many factors to be considered in optimising a solution, such as cost, availability of materials and impact on users and on the environment, which may constrain choices.

14-17

Science, engineering and technology are closely inter-connected. The application of science in making new materials is an example of how scientific knowledge has led advances in technology and provided engineers with a wider choice in designing constructions. At the same time technological advances have helped scientific developments by improving instruments for observation and measuring, automating processes that might otherwise be too dangerous or time consuming to undertake, and particularly through the provision of computers. Thus, technology aids scientific advances which in turn can be used in designing and making things for people to use. Often in the past technological products have been developed empirically in advance of scientific ideas, whilst today usually scientific understanding come first or at the same time. The application of science in designing and making new tools and machines has made mass production possible so more people have access to a range of commodities.

There are disadvantages as well as advantages to some technological products. Although the use of some artificial materials may mean less demand on scarce natural ones, many new materials do not degrade as do natural materials, presenting a waste disposal problem when discarded. Some technological devices such as mobile telephones and computers use metals that exist in the Earth only in small quantities and could soon be used up. Such examples reflect a wider problem, namely the need to recycle materials to conserve sources and to reduce pollution. When there are adverse effects on the environment which affect people's lives, scientists and engineers need to collaborate in understanding the problem and in finding solutions.

# 14 Applications of science often have ethical, social, economic and political implications

*The use of scientific knowledge in technologies makes many innovations possible. Whether or not particular applications of science are desirable is a matter that cannot be addressed using scientific knowledge alone. Ethical and moral judgments may be needed, based on such considerations as justice or equity, human safety and impacts on people and the environment.*

7-11

The understanding of the natural world that is developed through science enables us to explain how some things work or phenomena occur. This understanding can often be applied to change or make things to help solve human problems. Whilst such technological solutions have improved the lives and health of many people in countries across the world, it has to be recognised that they may use materials from the natural world which may be in short supply or may be detrimental to the environment.

11-14

There are generally both positive and negative consequences of the applications of science. Some negative impacts can be anticipated but others emerge from experience. Clean water, adequate food and improved medicines have increased human life expectancy but at the same time the resulting population growth has increased demands on resources and on space on the Earth's surface for increased food production, housing and disposal of waste. This has often been detrimental to those in developing countries and resulted in the destruction of habitats of other living things, causing some to become extinct.

There are many examples of how technological and engineering advances have unintended consequences. Improved ease and speed of transport, particularly by air, burns fuel that produces carbon dioxide, one of several gases in the atmosphere that keep the Earth warm through the greenhouse effect. Increase in these gases in the atmosphere raises the Earth's temperature. Even a small increase in temperature of the Earth can have widespread effects through changes in the polar ice, sea levels and weather patterns. If the detrimental effects are known, the trade-off between the advantages and the disadvantages of the application of science needs careful consideration.

14-17

All innovations consume resources of some kind including financial resources so decisions have to be made when there are competing demands. These decisions, whether at governmental, local or individual level, should be informed by understanding of the scientific concepts and the technological principles involved but decisions about action will be based on values and competing needs, not on the scientific evidence alone. Thus, when designing a new system or product engineers have to take account of ethical values, political and economic realities as well as science and technology.

Scientific understanding can help to identify implications of certain applications but decisions about whether certain actions should be taken will require ethical and moral judgements which are not provided by knowledge of science. There is an important difference between the understanding that science provides about, for example, the need to preserve biodiversity, the factors leading to climate change and the adverse effects of harmful substances and lifestyles, and the actions that may or may not be taken in relation to these issues. Opinions may vary about what action to take but arguments based on scientific evidence should not be a matter of opinion.

# 8

## ANNEX 2

# PLAYING WITH PROTONS GOES DIGITAL EDUCATIONAL SCENARIOS TEMPLATE

# 8 ANNEX 2: PLAYING WITH PROTONS GOES DIGITAL EDUCATIONAL SCENARIOS TEMPLATE

## Background information

**Title:** Give a title that helps easily recognise the content focus and purpose of the Art-based STEAM activity

**Brief Description:** Provide a description of no more than 30 words outlining the scope of the Art-based STEAM activity, descriptive enough to help the user in the first instance to estimate its possible relevance to her/his interests.

**Keywords:** A limited number of words/short phases reflecting the topic and scope.

**Target audience:** The intended end user(s): teacher with students, teacher, students, scientists, artists, others

**Age range:** e.g., 6-9, 9-12, 12-15, 15-18

**Context(s):** The place(s) that the Art-based STEAM activity involves: school, science museum/centre, research facility, independently on the web, combination of the above, etc.

**Time required:** The approximate time typically needed to realize the Art-based STEAM activity. This could be distinguished into the amount of time required for school-based work and out-of-school based work (e.g., visit to science museum/centre, homework, etc.)

**Technological tools required:** Description of any special technologies (e.g., AR), infrastructure (e.g., digital platform) and/or technical expertise required for the realization of the Art-based STEAM activity.

**Author(s)'s background:** What was the main function of the person who prepared the Art-based STEAM activity: school teacher; science museum/centre educator; science communicator, scientist, parent; combination of the above, etc.

**Connection with the curriculum:** Reference to the items of the science learning vocabulary mainly covered by the Art-based STEAM activity, and prerequisite knowledge.

**Learning objectives:** A short description of the objectives of the described Art-based STEAM activity and how these objectives relate to STEAM education. For example, you may want to describe briefly what the students will be doing in terms of Science, Technology, Engineering, Arts, and Mathematics.

**Guidance for preparation:** Guidance provided by the author(s) of the Art-based STEAM activity about any necessary arrangements that will need to be made by the interested teacher(s) before launching the activities described in the following sections.

TEMPLATE

# CREATE AN ARTWORK INSPIRED BY A SCIENTIFIC IDEA, PHENOMENON OR PROCESS

A suggested step-by-step guide for creating an artwork inspired by a scientific idea, phenomenon or process is to follow a scientific research-like process. To do so, students may want to utilize the following tools that can help them in the art making process:

- A *Journal* to record ideas, feelings, impressions, notes, test ideas;
- *Mindmaps* to help them unfold and connect with your narrative or messages your artwork intends to communicate to your audience;
- *Moodboards* to keep track of tools, ideas, methods, feelings, inspiration;
- A *Collection of Artworks* for inspiration and boosting creativity;
- A *Folder* to collect and share materials.

An example of such an approach is the following:

## 1. Setting the scene

Do a small hands-on activity related to the subject at hand so you can introduce the topic from a scientific point of view. As above, the activity could be a short scientific inquiry (experiment) or a hands-on STEM project.

Suggested Tools: Journal

## 2. Look around

Search on your subject for different types of Art related to your subject.

- Decide what type of artworks you are looking for (e.g., paintings, collages, sculptures, video installations, etc.);
- Look for renowned artists/artworks throughout the eras;

- Collect different artworks and select those that speak to you the most.

Suggested Tools: Journal

## 3. Investigation – Part 1

Elaborate on the artworks collected and try to understand what messages the artist is trying to convey and how she/he worked.

- Look for accompanying content on the artwork (description, commentary, artist's interview and trivia);
- Try and understand how the artist has worked to put the artwork together (methods, practices, process, tools, materials);
- Reflect on what the artwork means to each of the students;
- Reflect on what the artist is trying to say through her/his work.

Suggested Tools: Journal, Folder, Moodboard

## 4. Investigation – Part 2

Reflect on the artwork and understand what it means to the students. Encourage students to:

- Draw inspiration from the artwork collected;
- Reflect on what the message they want to communicate is;
- Think about ways to communicate their messages through different means of expression;
- Think about how the artworks studied can help students create their own art;

Suggested Tools: Journal, Moodboard, art activities

## 5. Creation

Create your own artwork. Students can:

- Deploy methods and processes and tools students learned about;
- Make a blueprint of their artwork;
- Experiment and try new things;
- Consider the use of technologies (e.g., AR) to help them communicate best the message(s) of their artwork
- Reflect on their work to see if the end product does communicate the message they wanted.

## 6. Communication and discussion

Present the artwork. Take some time and ask students to present their work. During this part you could do the following:

- Ask students to write an accompanying article talking about their art, their inspiration and the message they wished to communicate;
- Have a session where students present their artwork and ask other students to comment on it before the artist-student explains his/her point of view;
- Guide students to comment not on whether they like the artwork or not but on what they see/feel/think when looking at the artwork, what message does it communicate to them, what is the thing that engaged them most about it.
- Ask the artist-student to explain his/her point of view;
- Reflect and discuss on the artwork after the artist/student presents his/her rationale. Discuss whether new ideas for other artwork come up during the reflection session or if the artist/student would like to make some changes to the artwork.

<u>Suggested Tools:</u> Journal

## USE ART TO COMMUNICATE SCIENCE IN AN ENGAGING WAY

Another way to use art in conjunction with STEM is to invite students to become science communicators. According to this approach, students act as STEM ambassadors by getting engaged with activities that are closely related to activities that aim to open-up schools to local societies (Open Schooling approach). Students can create artworks around Science and STEM and then use them to inform their local communities about it and increase citizens' knowledge on STEM disciplines and their appreciation of them based on how they contribute in facing contemporary challenges and meet the needs of todays' societies. You can make this kind of activity as part of a bigger project that is based on the Open Schooling approach and integrate it as one of the tasks students will have to work on.

An example of such an approach is the following:

### 1. Setting the scene

Start your work again like in the setting the scene phase presented above so students can dive into the subject at hand. To achieve maximum impact, make sure the activity is directly related to everyday life or a contemporary problem. This way students will find meaning into what they are learning and be more engaged.

### 2. Conceptualisation

Ask you students to reflect on the activity they did and decide what are the main messages they wish to communicate through their art. After deciding on that, it is time to decide what kind of art they wish to create and if/how they will collaborate with their peers. Is it going to be a theatrical play? Is it going to be a painting? It is also a good idea to decide now how the final presentation of the entire class' work is going to happen and what kind of event you will organize (see more on the Discussion phase).

## 3. Investigation / Creation

Once the context is decided it is time for students to do research on the subject at hand so they can dive in and then create their Art. You can refer to the first section (Drawing inspiration from STEM) for more information on how to facilitate your students during this process. You can also use an inquiry science activity to help your students deepen their knowledge on the subject.

## 4. Demonstration / Reflection

Ask students to present their artworks and do a reflection session on them as described above so students can have a chance to receive feedback and possibly make some changes in their artwork. This phase will help your students' 'demo' their artwork and see if the message they wished to communicate is getting across to their audience.

## 5. Presentation

Once the artworks are finalized it is time to present them to the local community. This can be done in numerous ways. Here are some ideas:

- a school event where students' families and friends are invited;
- a local Science and Art festival;
- a social media campaign;
- a public event in a central point of their city or town.

Reviews from participants is what usually follows a premiere of a movie or an art exhibition. Likewise, regardless the way you choose to communicate students' work it is important to collect some feedback on the impact of the event to citizens. Consider putting together a small reflection questionnaire for participants or ask students to do some interviews. This way students can get an idea of how their work affected the local community and feel empowered to uptake more active roles in other citizen-related initiative as well.

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