Output 1

Best Outreach Practices Deliverable Report

Output 1 report produced by EA, EGO, DCU

List of Project partners DCU, EA, IASA, NUCLIO, PCCP, EGO

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Executive Summary

The FRONTIERS project brings together expertise from the fields of Particle Physics, Gravitational Wave Astronomy, Astrophysics, Cosmology and Astroparticle Physics, Science Education and Education in order to facilitate the introduction of frontier Physics in K12 education. To achieve this goal, the FRONTIERS consortium proposes a set of 25 best outreach practices, which can be used as a source of inspiration, to create a series of innovative educational scenarios. These best outreach practices have been identified using a set of quality criteria.

Intellectual Output 1 presents: a presentation of the best practices' evaluation criteria (Section 1), an overview of the selected best outreach practices with analysis (Section 2), a presentation of the analysis regarding the overall and individual characteristics of the proposed practices (Section 3) and the final conclusions and proposed outlook regarding the connection of the proposed practices with the FRONTIERS demonstrators.

Introduction

Throughout the last decades, a large effort in bringing frontier Physics in the classroom has taken place both in a national and international level [1] highly endorsed by leading European institutions in the field [2], [3]. Frontier Physics, a term used here to describe Particle, Astroparticle, Gravitational Wave Physics, Astrophysics and Cosmology, presents a great opportunity in bringing students closer to research and attracting them to scientific careers as it captures their imagination and motivates them. Furthermore, both the content knowledge as well as the ICT skills associated with it, provides a unique ground for teacher professional development. However, so far little progress has been made in integrating this cutting edge science in a systematic fashion in the High School curricula.

In the US, Quarknet [4], a national program for professional teacher development has been established since 1998 and following a scheme of connecting research centers, teachers and researchers, has contributed in the outreach of High Energy Physics (HEP) in high schools. Furthermore, it is using the trained teachers as ambassadors to attract and educate their colleagues and produce a multiplication effect. CERN [5], the largest European facility for High Energy Physics (HEP) research supports many initiatives and projects, hosts summer student and teacher-training programs, organizes competitions, and supports MasterClasses, experiments'-based initiatives and other activities [6].

In the framework of EU funded projects such as Learning with Discover the Cosmos [7], CREATIONS [8], innovative ICT-enhanced and creativity enriched inquiry based approaches such as Mini-Master classes, virtual Master classes and Virtual Visits in Research Centers [9] have been developed and implemented in educational interventions in many European Countries. Powerful particle physics data visualization and analysis tools such as HYPATIA [10] aiming to bridge the gap between scientific research and school education have been developed and largely implemented in European Schools.

IPPOG [11], the International Particle Physics Outreach Group has developed Master Classes with the help of CERN and Fermilab [12] which are widely used at schools and universities with the aim to train students in the LHC experimental data analysis and enhance the collaboration between students' groups from different countries.

In the field of Astroparticle Physics, national initiatives in Europe such as QuarkNet (US), EEE (Italy) [13], CERN@School (UK) [14], HiSPARK (NL) [15], Netzwerk Teilchenwelt (DE) [16] and others have done great work in bringing cosmic rays in their countries, building cosmic ray detectors to be placed in school and research center rooftops. However, up to the time of writing this document, these initiatives cannot reach further than their host country due to national policy and lack of funding. These projects are nationally funded and have almost all developed a partnership/collaboration with CERN. Inspired by the successful implementation of the CERN Masterclasses, the IceCube experiment [17], dedicated in the detection of cosmic neutrinos with a one-cubic-kilometer array of photosensitive sensors immersed deep in Antarctic Ice, has developed the IceCube Master classes [18] which introduce students in the Physics of Neutrinos and Astroparticle Neutrino detection.

In the newborn field of Gravitational Wave Astronomy, a series of steps have been made in the education and outreach sector from the pioneer experiments in the field, VIRGO in Europe and LIGO in the US, through site visits in the gravitational wave detector sites, the development of MOOCs that aim to introduce gravitational wave science in the general public, art and science initiatives that explore the connection of science and art in the field of gravitational wave and Astroparticle Physics, the development of dedicated lesson plans and activities as well as the development of citizen science projects. [19]

In the field of Astronomy several hands-on experiences with current trends in research in the field can be found, supporting the development of scientific experiments in cutting edge areas such as: search for asteroids, observing black hole candidates, studying extrasolar planets, fighting light pollution, etc. Major research infrastructures nowadays, provide free access to the data acquired for research purposes [20] allowing for the emergence of several outreach and education practices that support the integration of such data in the classroom in a user-friendly format.

Practices like the Global Hands On Universe [21] and European Hands On Universe [22] provide teachers with guidebooks and ideas of activities to do with students, using real robotic telescopes images and radio telescope data, to then process it with software like Astrometrica and Salsa J, making real scientific discoveries in class. The International Asteroid Search Collaboration [23] allows students to search for asteroids not discovered yet, playing an important role in contemporary Astronomy discoveries. Robotic telescopes like Faulkes telescope [24] have provided students with the opportunity to operate large-scale telescopes in class in real-time, exploring the night sky in different places of Earth. Dark Skies Rangers [25] raised students to real change makers in their localities by auditing the public lighting of their streets and making real calculations to plan and promote a sustainable street lighting. NASA currently provides students the opportunity to design experiments they would like to be done in space and submit them in the form of a 2min video to be actually taken to the International Space Station [26]. Teacher training initiatives, such as the Galileo Teacher Training Program [27], make use of such practices and motivate teachers and trainers in the use of such materials and promote an in depth knowledge of their use so that teachers feel confident to introduce them in their classes.

In sum, students can find several opportunities to act as real astronomers in their studies and often find their names in refereed papers where important discoveries are being reported. For teaches these are unique opportunities to involve their learners in hands-on science episodes where besides acquiring key skills they learn curriculum content in a very innovative and powerful way.

The initiatives discussed in this section present a fertile ground for integrating High Energy Physics and Astroparticle Physics in school practice. However, so far little progress has been made into integrating HEP in a systematic fashion in the High

School curricula across the world, with the foremost formal learning environment – the school – not providing the students with the opportunity to get closer to cutting edge fundamental research. In order to identify which outreach practices can be used as a source of inspiration for the FRONTIERS proposed activities - the FRONTIERS Demonstrators - an extensive study regarding already existent education and outreach practices across the world has been conducted. This study capitalizes on the vast experience of the project's consortium in the participation, design and implementation of education and outreach initiatives related to their specific fields of expertise. As a result, the outreach practices selected by the FRONTIERS consortium have not only been identified through a bibliographic research but also through the project partners' hands on experience throughout the last decade. To achieve that, a set of quality criteria have been applied in relation to the accessibility of these practices, their context, content, use of ICT, virtual labs and online databases, duration, impact, pedagogical significance and learning outcomes.

The initial sample of 32 outreach practices examined by the FRONTIERS consortium is presented in table 1.0. For each of these practices, an overview was provided by the partners who proposed them, along with measures for the impact of the practice's (duration, number of teachers and students engaged, years of implementation).

Name of Proposed Practice	Reference	Approved as FRONTIERS Best Outreach Practice	Comment
BeamLine 4 Schools	https://beamline-for-schools.web.cern.ch/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Cascade Competition	https://www.birmingham.ac.uk/schools/physics/outreach/secondary-schools/ cascade.aspx	Yes	Proposed practice fulfills FRONTIERS selection criteria

Cultural Collisions	http://artcms.web.cern.ch/ artcms/piece_of_news/a-walk-through-the-cultural- collisions-exhibition-in-the-ontario-science-centre/	Yes	Proposed practice fulfills FRONTIERS selection criteria
The interactive LHC tunnel	http://medialab.web.cern.ch/content/lhc-interactive-tunnel	Yes	Proposed practice fulfills FRONTIERS selection criteria
Code Week - The story of coding and coding exercises for high school students	http://public.virgo-gw.eu/tag/code-week-2017/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Gender-equality in science	http://public.virgo-gw.eu/Bright2018/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Multi-messenger Control Room	https://wiki.virgo-gw.eu/Main/SaracenoOnAirExhibition	Yes	Proposed practice fulfills FRONTIERS selection criteria
Site Visits	http://public.virgo-gw.eu/visit/	Yes	Proposed practice fulfills FRONTIERS selection criteria
International Physics Master classes	https://physicsmasterclasses.org/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Mini Particle Physics Master classes	https://doi.org/10.1051/epjconf/201713701012	Yes	Proposed practice fulfills FRONTIERS selection criteria
QuarkNET	https://quarknet.org	Yes	Proposed practice fulfills FRONTIERS selection criteria
Virtual Visits to LHC Experiments	https://atlasvirtualvisit.web.cern.ch/	Yes	Proposed practice fulfills FRONTIERS selection criteria
World Wide Data Day	https://quarknet.org/content/lhc-world-wide-data- day-2018	Yes	Proposed practice fulfills FRONTIERS selection criteria
BHIMS - Black Holes in My School	https://www.golabz.eu/ils/black-holes-in-my-school	Yes	Proposed practice fulfills FRONTIERS selection criteria

Bosemon - Learning particle physics through a game	https://sites.google.com/site/bosemongame/home	Yes	Proposed practice fulfills FRONTIERS selection criteria
DSR - Dark Skies Rangers	https://www.noao.edu/education/dsr.php	Yes	Proposed practice fulfills FRONTIERS selection criteria
IASC - International Astronomic Search Collaboration	http://iasc.hsutx.edu/	Yes	Proposed practice fulfills FRONTIERS selection criteria
(Radio-astronomy) Students use real time professional radio telescopes	http://euhou.obspm.fr/public/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Stories of Tomorrow (storytelling on a mission to mars)	http://www.storiesoftomorrow.eu/	Yes	Proposed practice fulfills FRONTIERS selection criteria
Sun4all	http://www.mat.uc.pt/sun4all/index.php/en/	Yes	Proposed practice fulfills FRONTIERS selection criteria
MOOC Gravity!	http://gravity.paris/en/index.php/category/blog/	Yes	Proposed practice fulfills FRONTIERS selection criteria
IceCube Master classes	https://masterclass.icecube.wisc.edu /en/node/129	Yes	Proposed practice fulfills FRONTIERS selection criteria
Cosmic Rays in the Classroom	http://www.hisparc.nl/en/; https://eee.centrofermi.it/; http://www.helycon.gr/HELYCON/HELYCON_in_a_nutshell.html ;	Yes	Proposed practice fulfills FRONTIERS selection criteria
Gravity Spy	https://www.zooniverse.org/projects/zooniverse/gravity- spy	Yes	Proposed practice fulfills FRONTIERS selection criteria

Muon Hunters	https://www.zooniverse.org/ projects/zooniverse/muon-hunter	Yes	Proposed practice fulfills FRONTIERS selection criteria
GraWIToN	http://www.grawiton-gw.eu/	No	This practice involved only graduate students
Alternanza Scuola- Lavoro	http://www.istruzione.it/ alternanza/	No	This practice involved only high school students
Hunting Exoplanets	N/A	No	This practice has not been implemented at a adequate level yet in order to be considered as a proposed best practice. The tools and methodology can be used as an inspiration for the development of a FRONTIERS Demonstrator.
Messier Marathon with Robotic Telescopes	https:// nightsky.jpl.nasa.gov/event-view.cfm?Event_ID=83657	No	This practice has not been implemented at a sufficient level in order to be considered as a proposed best practice yet. The tools and methodology can be used as an inspiration for the development of a FRONTIERS Demonstrator.
FERMI Master classes	https://agenda.infn.it/ conferenceDisplay.py? ovw=True&confId=15174	No	An emerging masterclass following the CERN Master classes using gamma ray data. Due to its short time of implementation, one cannot consider it a best outreach practice yet. The tools and methodology can be used as an inspiration for the development of a FRONTIERS Demonstrator.
Gamma Ray Hunters	http:// www.cazadoresderayosgamma .com/	No	A very nice app, which can be integrated in a FRONTIERS demonstrator, however there is no Impact characteristics available and it is presented only in one language so far. If available in other languages, the tools and methodology can be used as an inspiration for the development of a FRONTIERS Demonstrator.
Neutrino Masterclasses	http://neutrino-classroom.org/	No	Proposed to begin in 2018, this practice is promising yet at its infancy. The tools and methodology can be used as an inspiration for the development of a FRONTIERS Demonstrator.

Table 1.0: The outreach practices investigated by the FRONTIERS consortium

Using the first stage evaluation criteria, 25 best outreach practices have been identified and are described in detail in this document. To identify the pedagogical relevance of the 25 proposed best practices and the potential to be used as an inspiration for the development of the FRONTIERS demonstrators, a pedagogical framework has been designed and a set of "pedagogical relevance" criteria has been created.

1. Selection Criteria of Outreach Practices

1.1 First selection criteria

In order to select the best outreach practices out of those that have been examined, a set of 12 quality criteria in the form of questions have been applied using a Google form:

https://docs.google.com/forms/d/e/1FAIpQLSd6loSoGxPAR-aUFaA3fK_OZn-zXNeFYTw4RCCXHJL_VpT4rw/viewform.

These criteria as well as the rationale for their use can be found in Table 1.1. All the outreach practices investigated have junior or senior high school students as learners and in some cases they also include upper primary school students. Practices that involve only primary school pupils have not been examined on the grounds that the pedagogical impact of such initiatives is still under investigation.

	Quality Criterion	Options	Rationale
1	What is the scientific field of the proposed outreach practice? Choose at least one of the proposed subject fields	Particle Physics; Astroparticle Physics; Astrophysics; Gravitational Wave Astronomy; Cosmology	These are the subject fields relevant to the FRONTIERS project.

2	Has the proposed practice been implemented at least 3 times?	Yes; No	Following experience from other outreach initiatives, 3 implementations are considered enough for the practices to have obtained enough visibility within the research and education community.
3	Has the proposed practice been implemented with at least 100 students?	Yes; No	Following experience from other outreach initiatives, 100 students are considered enough for the practice to have obtained enough visibility within the research and education community.
4	Has the proposed practice engaged at least 10 educators?	Yes; No	Following experience from other outreach initiatives, 10 teachers are considered enough for the practice to have obtained enough visibility within the research and education community.
5	Does the proposed practice involve topics beyond the curricula of the countries it has been implemented in?	Yes; No	The proposed practices should involve topics beyond standard curricula overall, while, connections with the curricula are desired.
6	Is there any public reference of this practice?	Yes; No	Public reference is a measure of the visibility of the proposed practice.

7	If yes provide a link	Short text for URL	
8	Does the proposed outreach practice utilize existing research infrastructures of frontier research institutions?	Yes; No	The use of existing research infrastructures of a research institution is desired as it supports the authenticity of the proposed practice (for example the virtual visit in a research center provides students with a direct interaction with the center's infrastructure)
9	If yes, elaborate further	Short text for further description	
10	Does the proposed practice include use of online tools or web interactive educational material?	Yes; No	The use of online tools or web interactive educational material helps the personalization of the proposed practice and facilitates further the connection with the FRONTIERS Demonstrators, a specific characteristic of which will be the use of such tools.
11	Can the proposed outreach practice be utilized to create new activities to be used by students across the world: the Frontiers demonstrators?	Yes; No	This criterion investigates the relevance of the proposed practice with the FRONTIERS project and highlights the orientation of choosing best practices, aspects of which can be integrated in the

			FRONTIERS demonstrators.
12	If yes please describe briefly how	Short text for further description	

Table 1.1: First selection criteria for the evaluation of the proposed FRONTIERS best practices

The criteria presented in Table 1.1 were applied to the 32 examined practices (Table 1.0). Out of these, 25 best practices - described in Section 2 - have been found to fulfill the applied criteria and are thus proposed as FRONTIERS best outreach practices. The remaining best practices (Table 1.0, 3rd column) have been rejected either due to the fact that they have been implemented fewer times than the threshold we set (at least 3 implementations) or with less students/teachers than the threshold (at least 100 students and 10 teachers). Many of the proposed practices that have not been chosen as FRONTIERS best practices are quite new (less than 3 years since their conception) and as such, it is to be expected that their impact so far has been low. These are practices that the project consortium aims to support through the development of Demonstrators that will enhance their impact.

1.2 Second Selection Criteria

A second selection criteria was developed to gather very precise information about the outreach practices so that the pedagogical impact of the outreach practices could be determined. Dublin City University (DCU) conducted research to develop a pedagogical framework that would gather this information about the outreach practices.

This involved working over a 12-week period with 79 pre-service teachers. These pre-service teachers included students from the B.Sc. in Science Education, B.Sc. in Physical Education and Biology and B.Sc. in Physical Education and Math's. The students were attending DCU's Institute of Education module ES123: Foundation and Teaching Practice. The indicative content for ES123 included classroom planning and placement, reflective practice and self-evaluation, production of teaching resources, technology for educational contexts, introduction to expository and IB methods, communication skills and presentation skill development.

The TPACK framework (Figure 1.0) with its focus on technology, pedagogy and content knowledge was used as a base for developing the pedagogical framework to collect information about the outreach practices as it would take into account the kinds of knowledge needed by a teacher for effective pedagogical practice in a technology-enhanced learning environment. It consists of technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK). The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler) [28] consists of technology knowledge, content knowledge, and pedagogical knowledge.

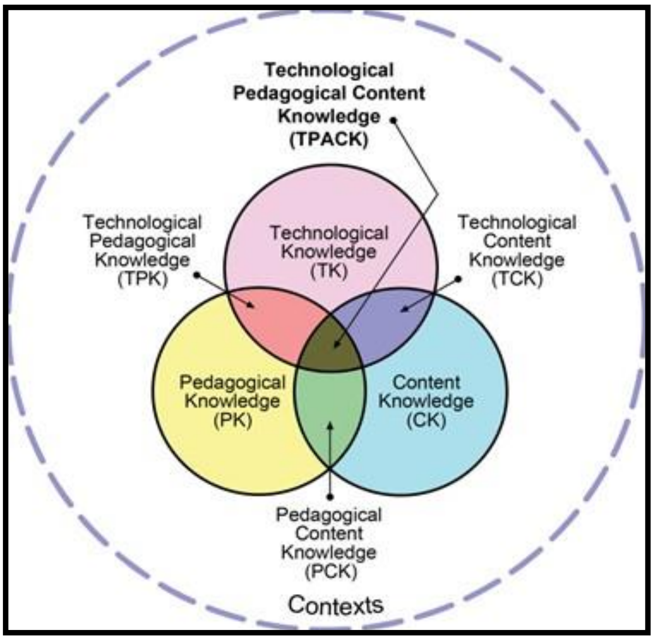


Figure 1.0. TPACK Framework (Reproduced by permission of the publisher, © 2012 by tpack.org).

The second selection criteria therefore consisted of (i). the technology/ tools, which are the outreach practices themselves, (ii). the pedagogical knowledge, with a focus on inquiry, and the content knowledge, which is the Physics knowledge.

In relation to pedagogical knowledge (PK) there are many different types of inquiry-based frameworks. A 7-stage framework was created which includes; 1). question, 2). evidence, 3). analyse, 4). explain, 5). connect, 6). communicate and 7). reflect. The 7 stages are embedded within a 3-stage process - Orientation, Exploratory and

Consolidation.

According to Shulman [29] and later Ball et al. [30] and Robinson's [31], Content knowledge (CK) means knowledge of the subject, the central principles, tenets and established structures, which define the subject matter content. This knowledge also includes beliefs about what is important for students to understand. The subject matter content deals with the base units of a subject or topic, the particular facts or concepts which define that subject and sets it aside from other topics (Shulman [32], Robinson [31]). For the purpose of selection of the outreach practices, the content of an outreach practice refers to its content knowledge e.g. Physics and inherent subject matter e.g. particle physics.

The analysis of content material within the science of teaching is known as 'pedagogical analysis of the contents' (Bhowmik et al.) [33] In carrying out a pedagogical analysis of the outreach practices, descriptive metadata was gathered. This is a set of structured information that describes and gives information about other data. This descriptive metadata will describe the educational content of the outreach practices, and will be used to analyse the outreach practices.

For the purposes of Output 1 and to address the pedagogical impact and relevance of the outreach practices, Content Knowledge (CK) became the focus of this Output and the basis for the pedagogical framework for the selection of the outreach practices. The metadata evaluation for each outreach practice was broken into two units:

1). Topic and 2) Learning Outcomes.

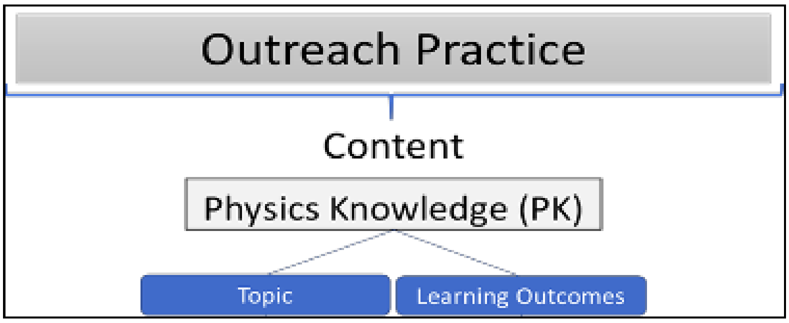


Figure 1.1 – Outreach Practices Content Analysis Units

1. **Topic** is defined as particular areas of physics (e.g. astrophysics) with common traits. To categorise 'topic' was divided it into three sub-units; Themes or Concept, Aims & Goals and Subject Matter.

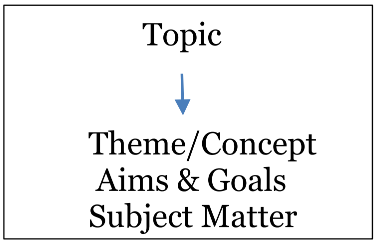


Figure 1.2 – Sub-Units under which the Outreach Practice Topic Content is analysed

2. Learning Outcomes are statements that define the expected goal of a curriculum, course, lesson or activity in terms of demonstrable skills or knowledge that student will be able to do as a result of an outreach practice. Learning outcomes are divided into one sub-units called Statements.

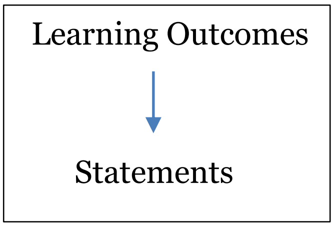


Figure 1.3 Sub-Unit under which the Outreach Practice Learning Outcomes Content is analysed

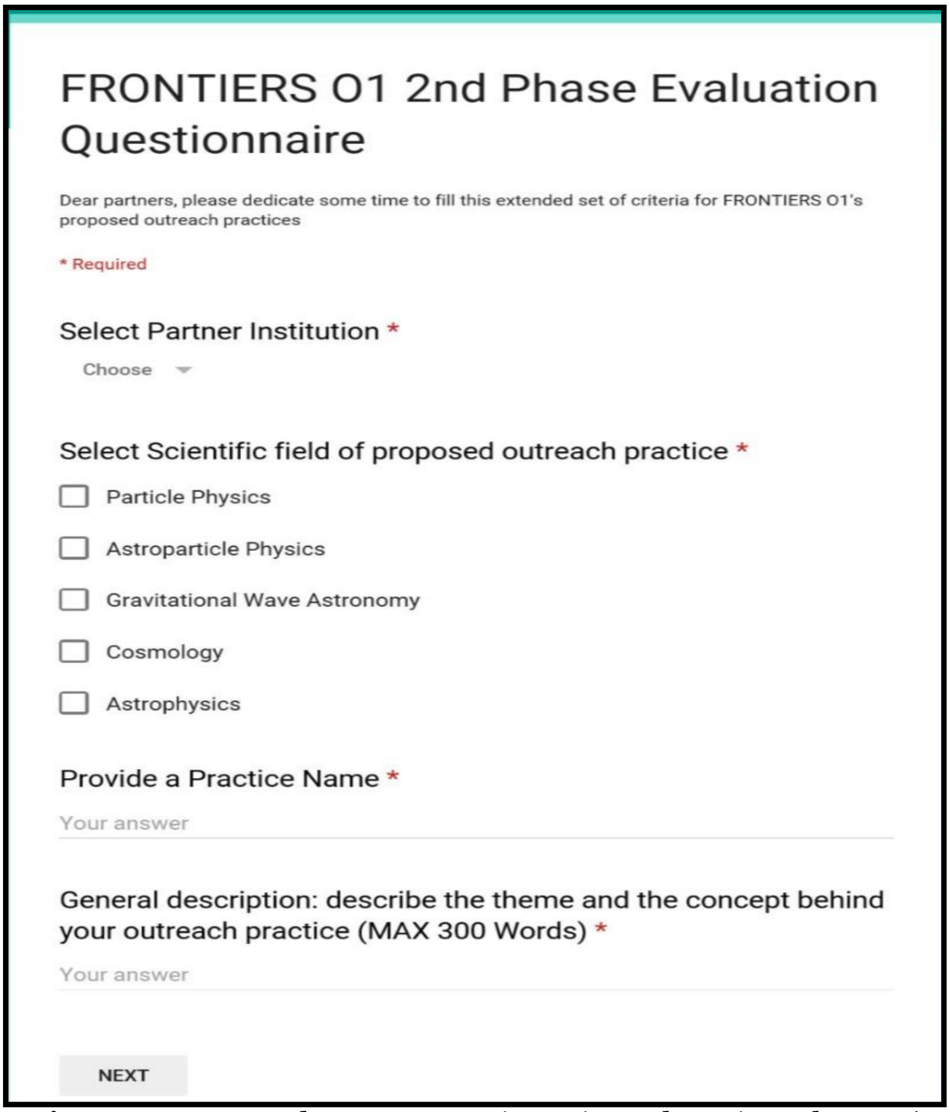
To carry out a pedagogical analysis of the outreach practices the above units and sub-units were formulated into a Google form questionnaire

Pedagogical Analysis of Outreach Practices Content: Google Form Questionnaire.

Unit 1 Outreach Practice Topic Analysis

Sub-Unit – Theme/Concept

The first sub-unit consisted of Theme or Concept (Figure 1.4) and explains the general characteristics of the practice e.g. the scientific field, name of the practice, the general description and key concepts. This sub-unit aimed to characterise the underlying topic and grouping it under common themes).



FRONTIERS O1 2nd Phase Evaluation Questionnaire

Dear partners, please dedicate some time to fill this extended set of criteria for FRONTIERS O1's proposed outreach practices

* Required

Select Partner Institution *

Choose

Select Scientific field of proposed outreach practice *

- [ ] Particle Physics
- [ ] Astroparticle Physics
- [ ] Gravitational Wave Astronomy
- [ ] Cosmology
- [ ] Astrophysics

Provide a Practice Name *

Your answer

General description: describe the theme and the concept behind your outreach practice (MAX 300 Words) *

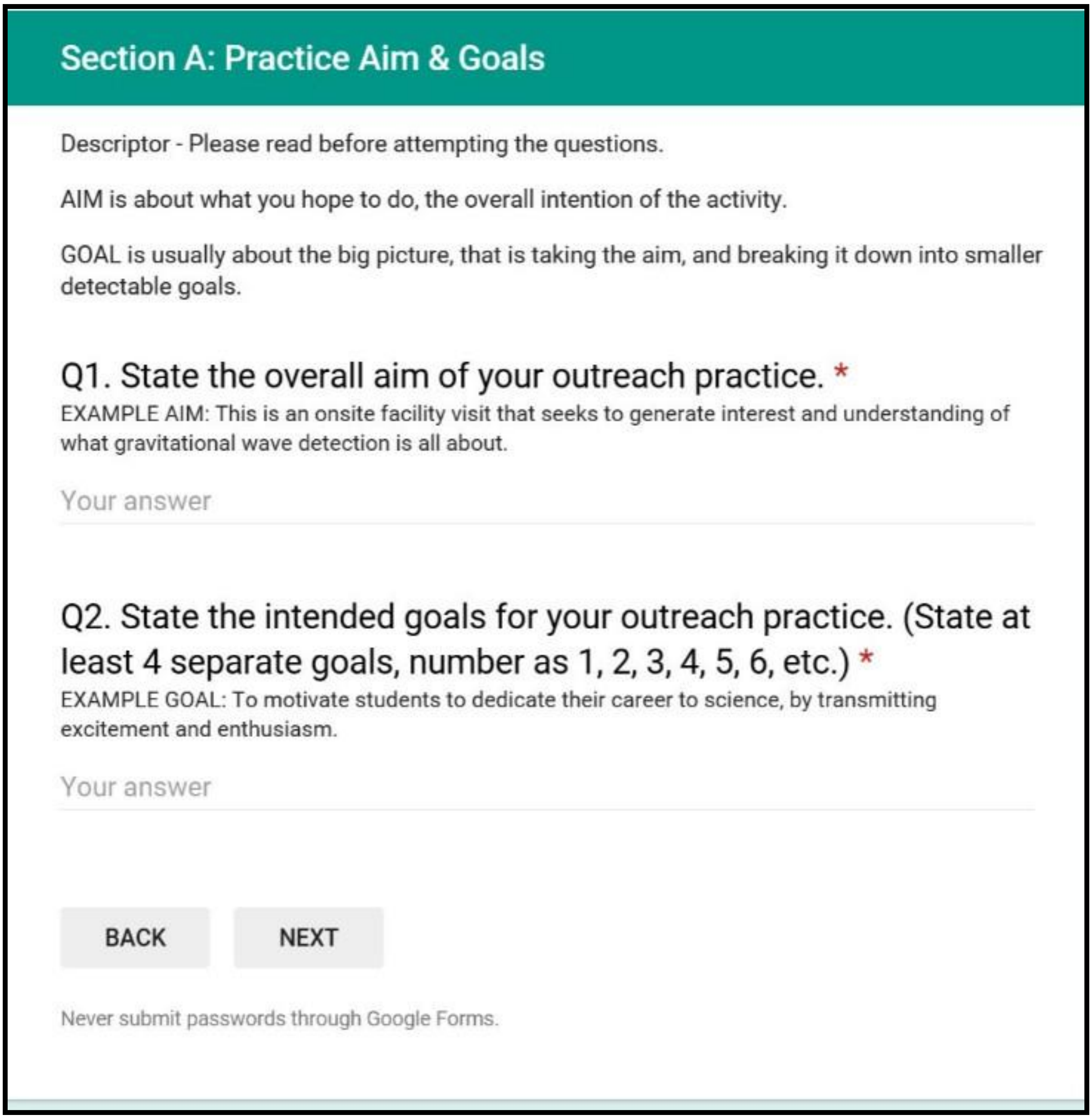
Your answer

NEXT

Figure 1.4 – Google Form Questionnaire Sub-Unit – Themes/Concept

Unit 1: Sub-Unit – Section A Practice Aims and Goals

Section A of the template (Figure 1.5) was designed to gather the aims and goals of the outreach practice. The purpose of this sub-unit was to characterise the general educational aim or specific goals of the outreach practice.



Section A: Practice Aim & Goals

Descriptor - Please read before attempting the questions.

AIM is about what you hope to do, the overall intention of the activity.

GOAL is usually about the big picture, that is taking the aim, and breaking it down into smaller detectable goals.

Q1. State the overall aim of your outreach practice. *

EXAMPLE AIM: This is an onsite facility visit that seeks to generate interest and understanding of what gravitational wave detection is all about.

Your answer

Q2. State the intended goals for your outreach practice. (State at least 4 separate goals, number as 1, 2, 3, 4, 5, 6, etc.) *

EXAMPLE GOAL: To motivate students to dedicate their career to science, by transmitting excitement and enthusiasm.

Your answer

BACK NEXT

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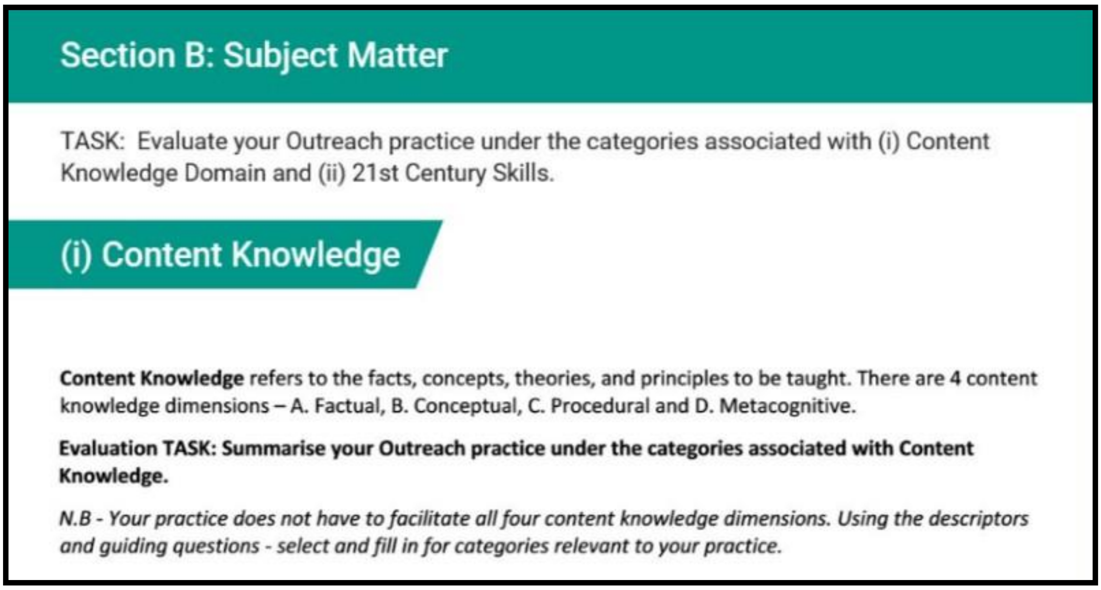
Figure 1.5 – Google Form Questionnaire Sub-Unit – Aims and Goals

Unit 1 Sub-Unit – Section B Subject Matter

Section B of the template (Figure 1.6) dealt with the subject matter of the outreach practice. Subject matter was divided into two content areas, 1). content knowledge (Figure 1.6) and (2. 21st century skills (Figure 1.13).

Firstly, we will look at the analysis of the content knowledge of the outreach practice.

(i) **Content Knowledge** refers to the facts, concepts, theories, and principles within the practice.


Section B: Subject Matter

TASK: Evaluate your Outreach practice under the categories associated with (i) Content Knowledge Domain and (ii) 21st Century Skills.

(i) Content Knowledge

Content Knowledge refers to the facts, concepts, theories, and principles to be taught. There are 4 content knowledge dimensions – A. Factual, B. Conceptual, C. Procedural and D. Metacognitive.

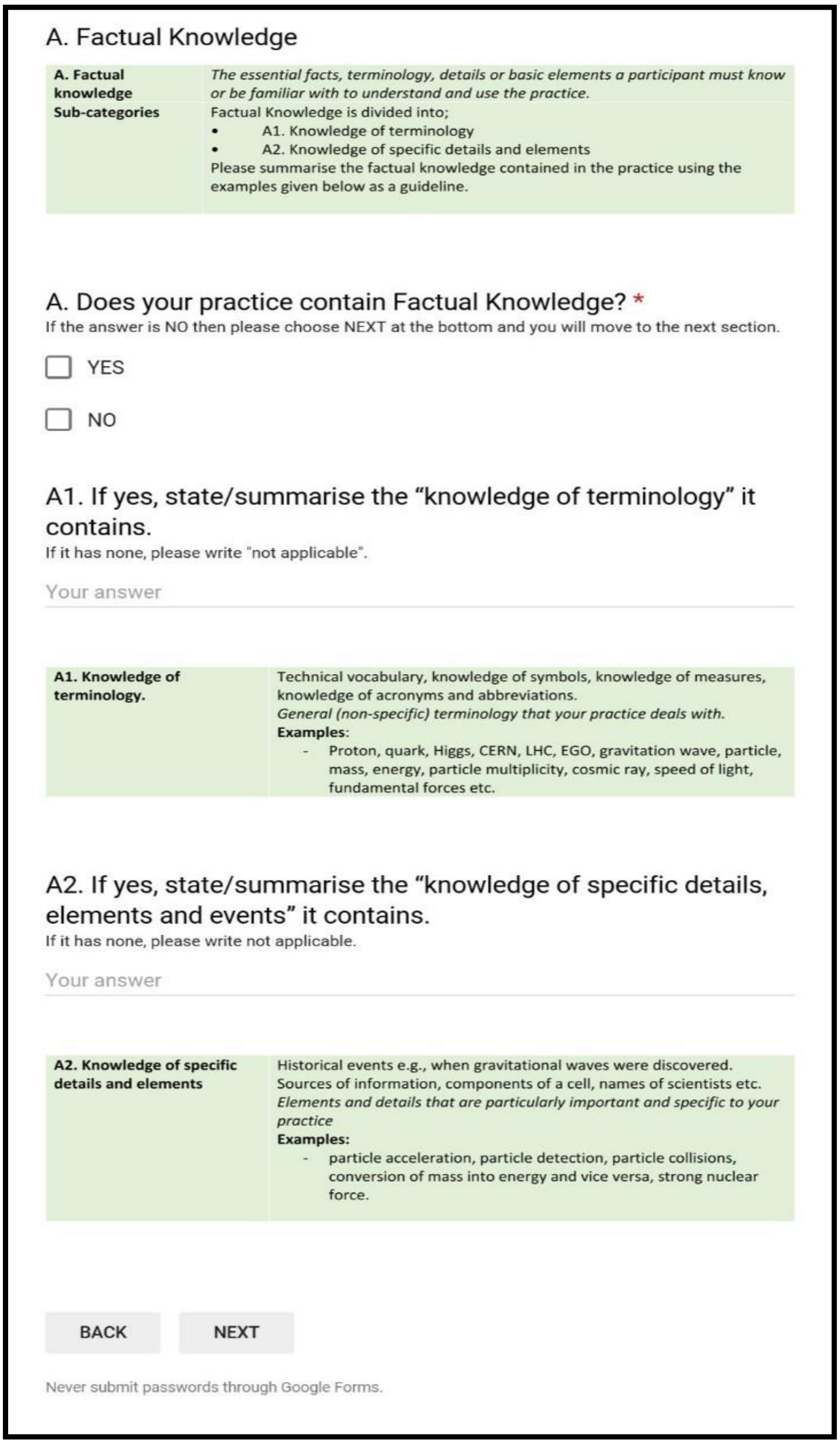
Evaluation TASK: Summarise your Outreach practice under the categories associated with Content Knowledge.

N.B - Your practice does not have to facilitate all four content knowledge dimensions. Using the descriptors and guiding questions - select and fill in for categories relevant to your practice.

Figure 1.6 – Google Form Questionnaire Sub-Unit – Subject Matter (1. Content Knowledge

Bloom's [34] taxonomy of knowledge dimensions provided a useful framework for analysing content knowledge. These knowledge dimensions were revised and extended by Anderson et al. [35] to include metacognitive. Adapting Anderson et al.'s model with descriptors and sample answers, partners were asked to summarise their outreach practice under the four cognitive knowledge categories. These include (i). factual, (ii). conceptual, (iii). procedural and (iv). metacognitive knowledge as shown below.

A Factual Knowledge



A. Factual Knowledge

A. Factual knowledge	*The essential facts, terminology, details or basic elements a participant must know or be familiar with to understand and use the practice.*
Sub-categories	Factual Knowledge is divided into; • A1. Knowledge of terminology • A2. Knowledge of specific details and elements Please summarise the factual knowledge contained in the practice using the examples given below as a guideline.

A. Does your practice contain Factual Knowledge? *

If the answer is NO then please choose NEXT at the bottom and you will move to the next section.

- [ ] YES
- [ ] NO

A1. If yes, state/summarise the "knowledge of terminology" it contains.

If it has none, please write "not applicable".

Your answer

A1. Knowledge of terminology.	Technical vocabulary, knowledge of symbols, knowledge of measures, knowledge of acronyms and abbreviations. *General (non-specific) terminology that your practice deals with.* **Examples:** - Proton, quark, Higgs, CERN, LHC, EGO, gravitation wave, particle, mass, energy, particle multiplicity, cosmic ray, speed of light, fundamental forces etc.

A2. If yes, state/summarise the "knowledge of specific details, elements and events" it contains.

If it has none, please write not applicable.

Your answer

A2. Knowledge of specific details and elements	Historical events e.g., when gravitational waves were discovered. Sources of information, components of a cell, names of scientists etc. *Elements and details that are particularly important and specific to your practice* **Examples:** - particle acceleration, particle detection, particle collisions, conversion of mass into energy and vice versa, strong nuclear force.

BACK NEXT

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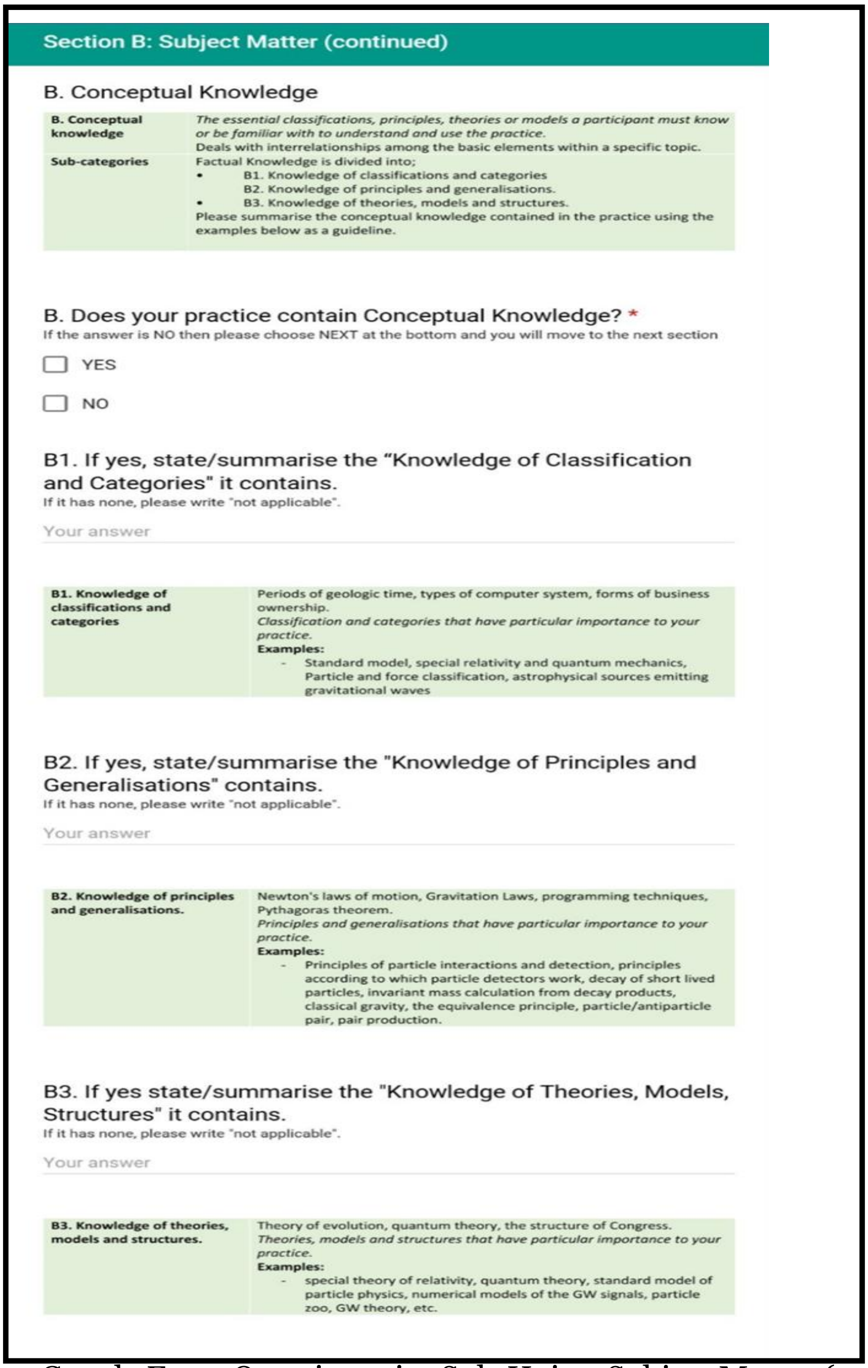
Figure 1.7 – Google Form Questionnaire Sub-Unit – Subject Matter
(i) Content Knowledge: A Factual Knowledge

B Conceptual Knowledge



Section B: Subject Matter (continued)

B. Conceptual Knowledge

B. Conceptual knowledge	*The essential classifications, principles, theories or models a participant must know or be familiar with to understand and use the practice.* Deals with interrelationships among the basic elements within a specific topic.
Sub-categories	Factual Knowledge is divided into; • B1. Knowledge of classifications and categories B2. Knowledge of principles and generalisations. • B3. Knowledge of theories, models and structures. Please summarise the conceptual knowledge contained in the practice using the examples below as a guideline.

B. Does your practice contain Conceptual Knowledge? *

If the answer is NO then please choose NEXT at the bottom and you will move to the next section

☐ YES

☐ NO

B1. If yes, state/summarise the "Knowledge of Classification and Categories" it contains.

If it has none, please write "not applicable".

Your answer

B1. Knowledge of classifications and categories	Periods of geologic time, types of computer system, forms of business ownership. *Classification and categories that have particular importance to your practice.* **Examples:** - Standard model, special relativity and quantum mechanics, Particle and force classification, astrophysical sources emitting gravitational waves

B2. If yes, state/summarise the "Knowledge of Principles and Generalisations" contains.

If it has none, please write "not applicable".

Your answer

B2. Knowledge of principles and generalisations.	Newton's laws of motion, Gravitation Laws, programming techniques, Pythagoras theorem. *Principles and generalisations that have particular importance to your practice.* **Examples:** - Principles of particle interactions and detection, principles according to which particle detectors work, decay of short lived particles, invariant mass calculation from decay products, classical gravity, the equivalence principle, particle/antiparticle pair, pair production.

B3. If yes state/summarise the "Knowledge of Theories, Models, Structures" it contains.

If it has none, please write "not applicable".

Your answer

B3. Knowledge of theories, models and structures.	Theory of evolution, quantum theory, the structure of Congress. *Theories, models and structures that have particular importance to your practice.* **Examples:** - special theory of relativity, quantum theory, standard model of particle physics, numerical models of the GW signals, particle zoo, GW theory, etc.

Figure 1.8 – Google Form Questionnaire Sub-Unit – Subject Matter (1. Content Knowledge: B. Conceptual Knowledge.

C. Procedural Knowledge

C. Procedural Knowledge

C. Procedural knowledge	*The essential skills, algorithms, techniques, methods and criteria participant must know or be familiar with to understand and use the practice.* Refers to information or knowledge that helps students to do something specific within the area of study, e.g., methods of inquiry, very specific or finite skills, algorithms, techniques, and methodologies.
Sub-categories	Procedural Knowledge is divided into; • C1. Knowledge of subject-specific skills and algorithms. • C2. Knowledge of subject-specific techniques and methods. • C3. Knowledge of criteria for determining when to use appropriate procedures. Please summarise the procedural knowledge contained in the practice using the examples below as a guideline.

C. Does your practice contain Procedural Knowledge? *

If the answer is NO then please choose NEXT at the bottom and you will move to the next section

- [ ] YES
- [ ] NO

C1. If yes, state/summarise the "Knowledge of Subject-Specific Skills and Algorithms" it contains.

If it has none, please write "not applicable".

Your answer

C1. Knowledge of subject-specific skills and algorithms.	*Subject-specific skills and algorithms that have particular importance to your practice.* Knowledge of how to engage in science related activities, higher order thinking and learning skills, science specific skills and algorithms **Examples:** - *High-order skills*: e.g., inquiry-based learning, problem-solving. - *Subject specific (science) skills:* Skill area 1 - Information retrieval (e.g. books, library, experts and internet). Skill area 2 - Listening and observing (e.g. presentations and to video). Skill area 3 - Scientific reading (e.g. articles and textbooks). Skill area 4 - Data representation (e.g. by symbols, diagrams, graphs and tables). Skill area 5 - Scientific writing (e.g. reports, case studies, papers, abstracts and bibliographies). Skill area 6 - Knowledge presentation (e.g. oral presentation, multimedia and poster). - *Algorithms*: such as Equation to represent particle collision, Equation to represent particle decay, LHC Particle collisions Mass/Energy Calculations, Pair production/Annihilation calculations.

C2. If yes, state/summarise the "Knowledge of Subject-Specific Techniques and Methods" it contains.

If it has none, please write "not applicable".

Your answer

C2. Knowledge of subject-specific techniques and methods.	Knowledge of Scientific Method, Specific Experimental procedures *Subject specific techniques that have particular importance to your practice.* **Examples:** - experimental techniques and methods for particle accelerators/detection (e.g. Linear particle accelerator, large hadron collider), measurement of specific parameters (e.g. particle charge, momentum, velocity, tracks), techniques and methods to communicate science.

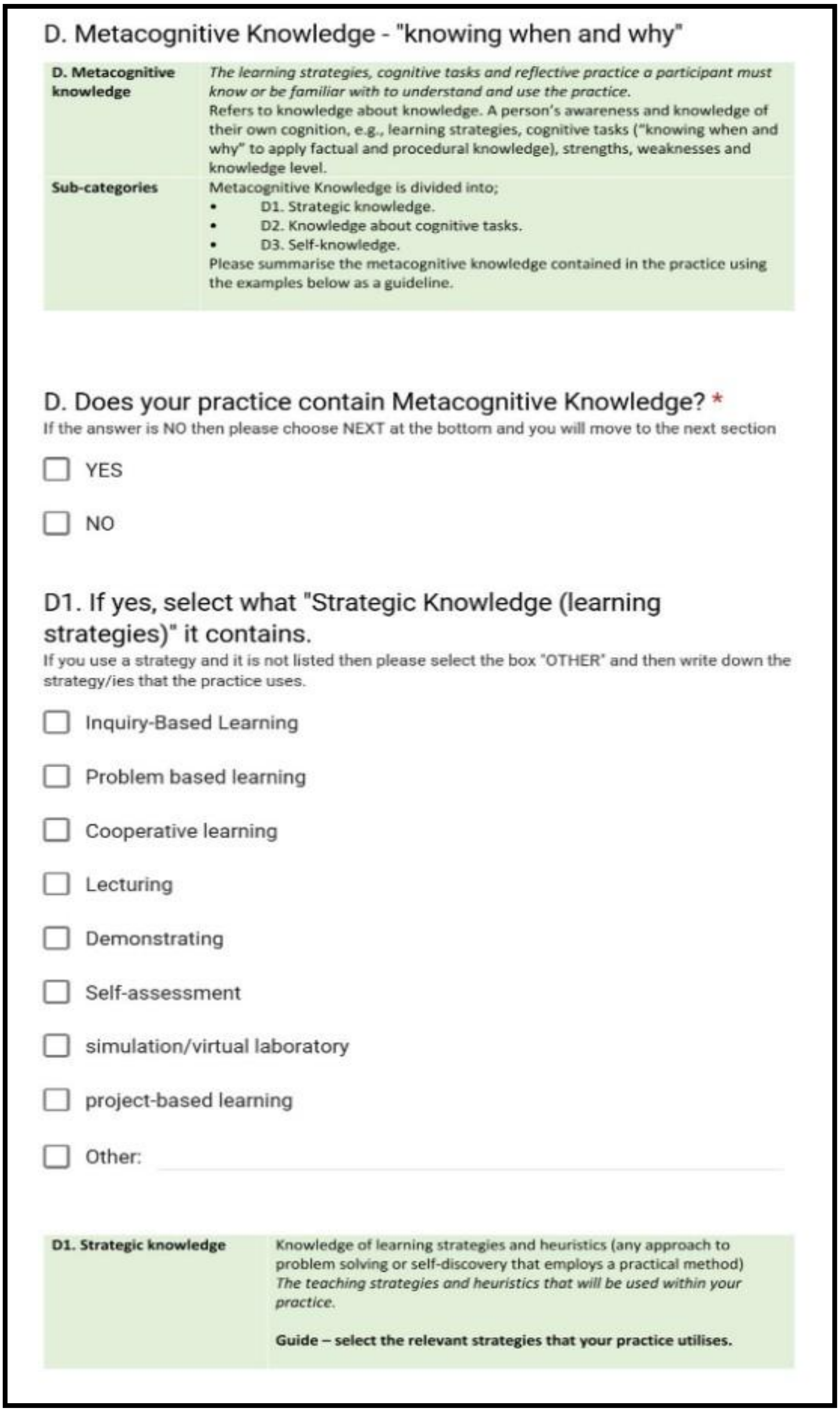
C3. If yes, state/summarise the "Knowledge of Criteria for Determining when to use Appropriate Procedures" it contains.

If it has none, please write "not applicable".

Your answer

Figure 1.9 – Google Form Questionnaire Sub-Unit – Subject Matter (1. Content Knowledge: C. Procedural Knowledge

D. Metacognitive



D. Metacognitive Knowledge - "knowing when and why"

D. Metacognitive knowledge	*The learning strategies, cognitive tasks and reflective practice a participant must know or be familiar with to understand and use the practice.* Refers to knowledge about knowledge. A person's awareness and knowledge of their own cognition, e.g., learning strategies, cognitive tasks ("knowing when and why" to apply factual and procedural knowledge), strengths, weaknesses and knowledge level.
Sub-categories	Metacognitive Knowledge is divided into; • D1. Strategic knowledge. • D2. Knowledge about cognitive tasks. • D3. Self-knowledge. Please summarise the metacognitive knowledge contained in the practice using the examples below as a guideline.

D. Does your practice contain Metacognitive Knowledge? *

If the answer is NO then please choose NEXT at the bottom and you will move to the next section

- [ ] YES
- [ ] NO

D1. If yes, select what "Strategic Knowledge (learning strategies)" it contains.

If you use a strategy and it is not listed then please select the box "OTHER" and then write down the strategy/ies that the practice uses.

- [ ] Inquiry-Based Learning
- [ ] Problem based learning
- [ ] Cooperative learning
- [ ] Lecturing
- [ ] Demonstrating
- [ ] Self-assessment
- [ ] simulation/virtual laboratory
- [ ] project-based learning
- [ ] Other:

D1. Strategic knowledge	Knowledge of learning strategies and heuristics (any approach to problem solving or self-discovery that employs a practical method) *The teaching strategies and heuristics that will be used within your practice.* **Guide – select the relevant strategies that your practice utilises.**

Figure 1.10 – Google Form Questionnaire Sub-Unit – Subject Matter (1. Content Knowledge: <u>D. Metacognitive Knowledge Part 1.</u>

D2. If yes, state/summarise how a participant will apply the selected learning strategy/ies within the practice.

Your answer

D2. Knowledge about cognitive tasks	Knowledge about how to employ a learning strategy, method and heuristics within subject specific tasks. *How student will employ the selected learning strategies and heuristics within your practice.* **Guide – referring to the learning strategies selected above in D1, explain with reference to your practice how a participant will apply the strategy(ies).**

D3. Does the practice allow a participant to self-reflect?

If the answer is NO then please choose NEXT at the bottom and you will move to the next section.

- [ ] YES
- [ ] NO

D3. Self-knowledge	Knowledge and awareness of personal strengths and weaknesses, awareness of extent of own knowledge about a topic. *The reflective practice techniques used within your practice that enables a participant to reflect on their current knowledge level, strengths and weaknesses.* **Guide – describe how your practice enables a student to reflect on what they currently know, what they have learnt (new knowledge) and where they need to improve (weaknesses).**

D3. If yes, how does the practice enable self-reflection?

Your answer

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Figure 1.11 – Google Form Questionnaire Sub-Unit – Subject Matter (1. Content Knowledge: D. Metacognitive Knowledge Part 2.

The following table shows the percentage of yes and no responses for the different types of content knowledge contained in the outreach practices.

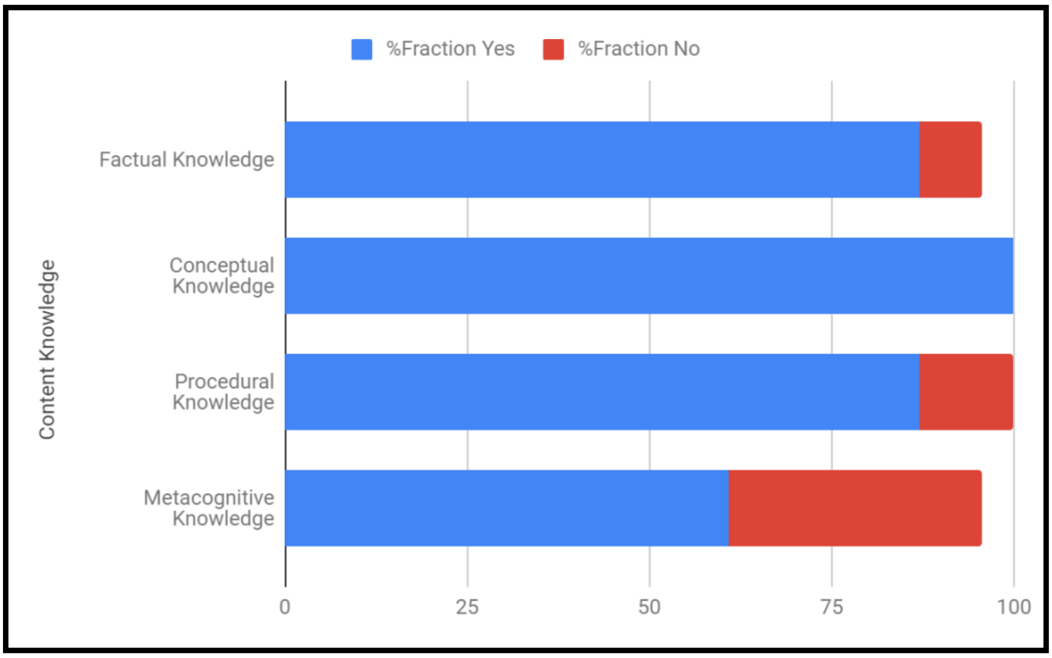
Content Knowledge	% Fraction Yes	%Fraction No
Factual Knowledge	86.95652174	8.695652174
Conceptual Knowledge	100	0
Procedural Knowledge	86.95652174	13.04347826
Metacognitive Knowledge	60.86956522	34.7826087

Table 1.3 Table of Evaluated Practices for Content Knowledge

From the graph it is clear that metacognitive knowledge is not fully developed in all of the practices.

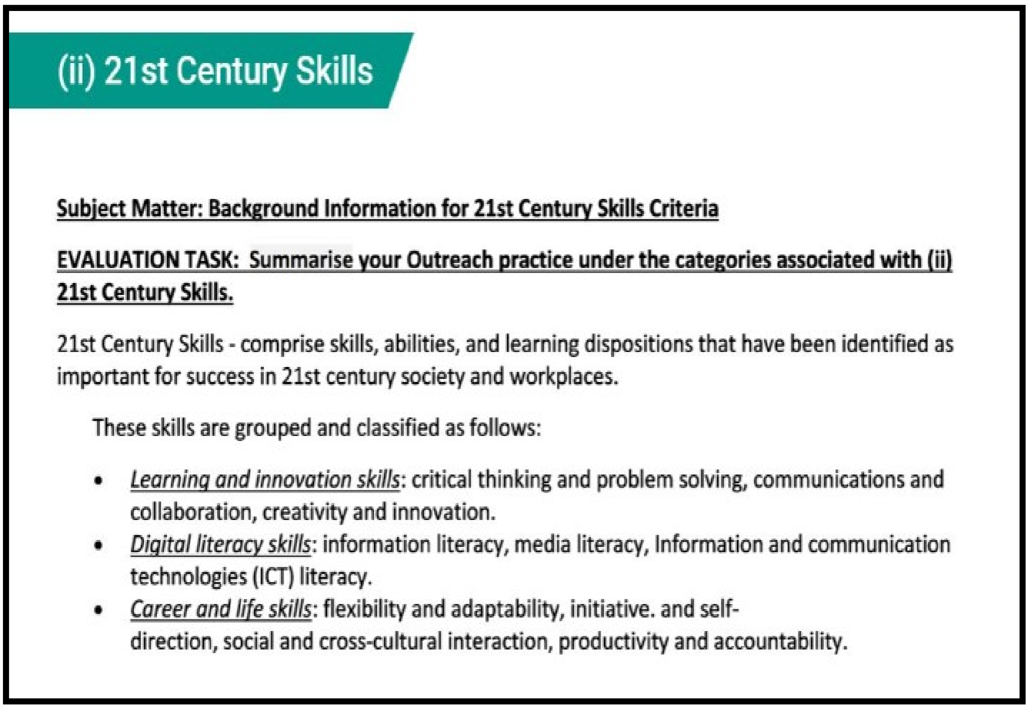
Many of the outreach practices are of a short duration so it may not be possible to develop these skills within a short time frame, however as they are important skills. These will be explored further in the development of the demonstrators.

Figure 1.12 – Graphic Analysis of Evaluated Practices for Content Knowle



Having analysed the content knowledge, the 21st century skills were then examined.

(ii). **21st century** skills refer to a set of abilities that students will require if they are to succeed in today's workplace and society.



(ii) 21st Century Skills

Subject Matter: Background Information for 21st Century Skills Criteria

EVALUATION TASK: Summarise your Outreach practice under the categories associated with (ii) 21st Century Skills.

21st Century Skills - comprise skills, abilities, and learning dispositions that have been identified as important for success in 21st century society and workplaces.

These skills are grouped and classified as follows:

- *Learning and innovation skills*: critical thinking and problem solving, communications and collaboration, creativity and innovation.
- *Digital literacy skills*: information literacy, media literacy, Information and communication technologies (ICT) literacy.
- *Career and life skills*: flexibility and adaptability, initiative. and self-direction, social and cross-cultural interaction, productivity and accountability.

Figure 1.13 – Google Form Questionnaire Sub-Unit – Subject Matter (2. 21st Century Skills)

The 21st Century Skills includes critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurialism, effective oral and written communication, accessing and analysing information and curiosity and imagination Wagner [36]. These skills have been identified by teachers, educational researchers, policy makers, politicians and employers as essential for success in 21st century society (Levy and Munane [37]; National Research Council [38] ; Dede [39]; Kalantzis and Cope [40]) .

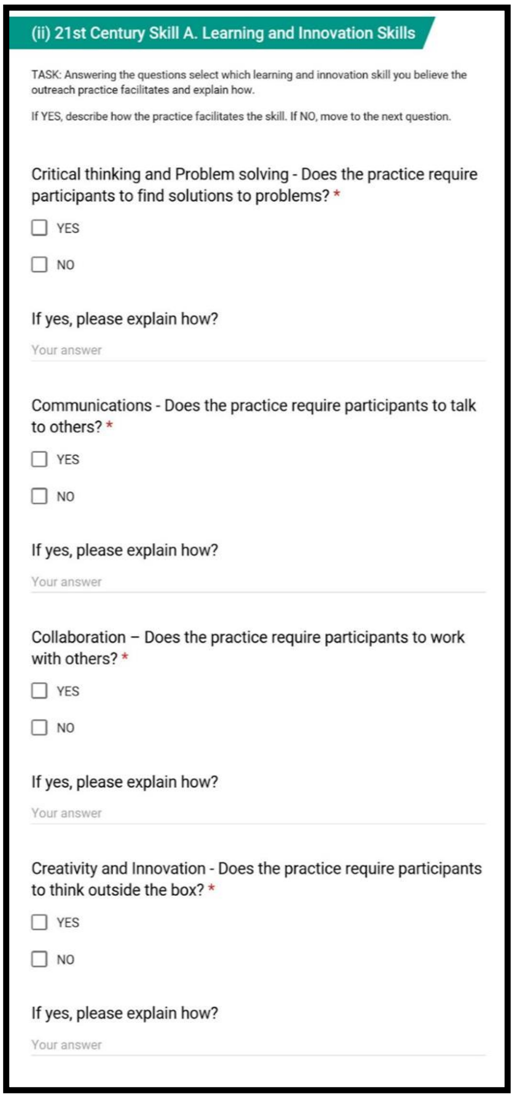
While students engage in the study of science related topics, it has been proposed that individuals learn and apply these 21st century skills, Levy and Murnane [37]; Bybee [41]. To identify the skills contained within the outreach practices, the Partnership for 21st Century Learning (P21) [42] framework (P21, 2011) was adapted. Using descriptors with sample answers, partners were asked to analysis and summaries their outreach practices under the following categories associated with 21st Century Skills:

A. Learning and innovation skills: critical thinking and problem solving, communications and collaboration, creativity and innovation.

B. Digital literacy skills: information literacy, media literacy, Information and communication technologies (ICT) literacy.

C. Career and life skills: flexibility and adaptability, initiative and self-direction, social and cross-cultural interaction, productivity and accountability.

A. Learning and innovation skills



(ii) 21st Century Skill A. Learning and Innovation Skills

TASK: Answering the questions select which learning and innovation skill you believe the outreach practice facilitates and explain how.

If YES, describe how the practice facilitates the skill. If NO, move to the next question.

Critical thinking and Problem solving - Does the practice require participants to find solutions to problems? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Communications - Does the practice require participants to talk to others? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Collaboration – Does the practice require participants to work with others? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Creativity and Innovation - Does the practice require participants to think outside the box? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Figure 1.14 – Google Form Questionnaire Sub-Unit – Subject Matter (2. 21st Century Skills: A. Learning and Innovation Skills.

Table 1.3 shows the percentage of yes and no responses to the 21st Century Skills of learning and innovation contained in the best practices.

21st Century Skill A. Learning and Innovation Skills	% Fraction Yes	% Fraction No
Critical thinking and Problem solving	73.91304348	26.08695652
Communication	82.60869565	17.39130435
Collaboration	78.26086957	21.73913043
Creativity and Innovation	73.91304348	26.08695652

Table 1.3 Table of Evaluated Practices for 21st Century Skills A. Learning and Innovation Skills.

It is a positive to see from the graph that a high number of the practices (over 75%) include collaboration and communications. Critical thinking, problem solving and creativity and innovation are presented in over 70% of the outreach practices. As these are also important skills for the 21st century then we will explore if these skills can be included when developing the demonstrators.

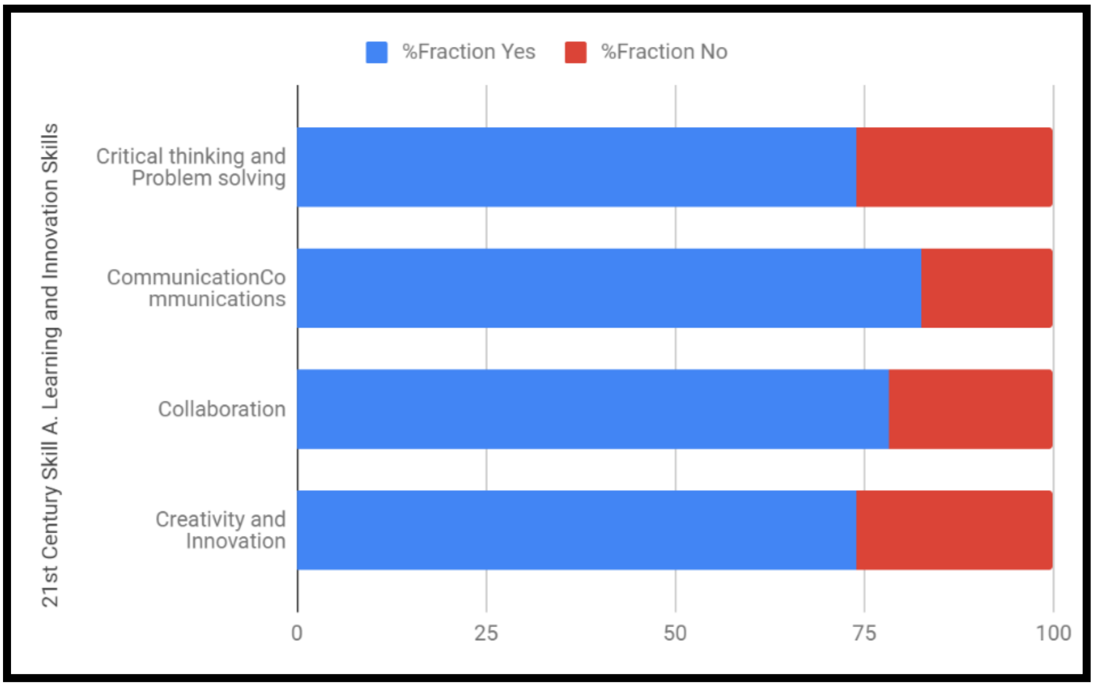
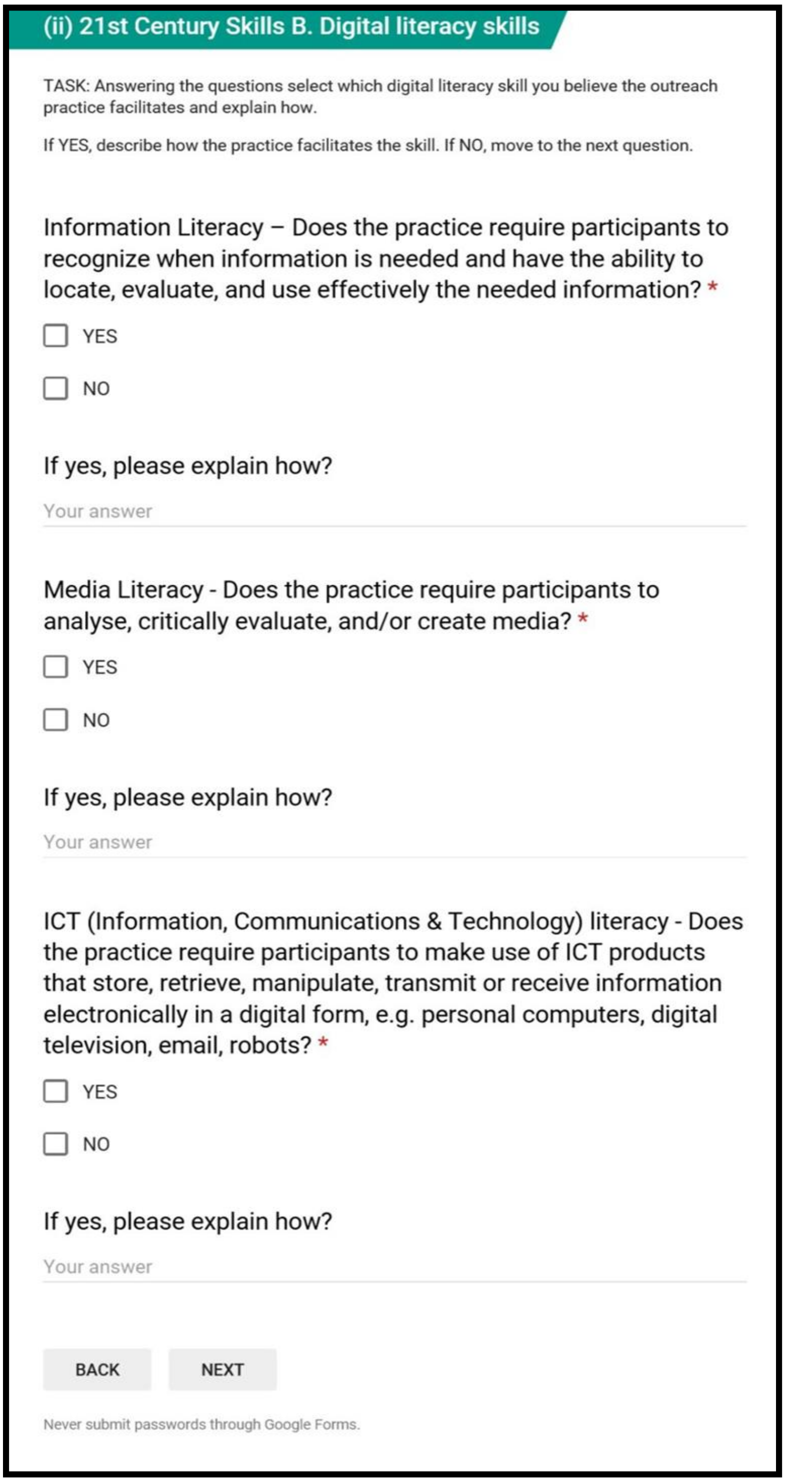


Figure 1.15 – Graphic Analysis of Evaluated Practices for 21st Century Skills A. Learning and Innovation Skills

B. Digital literacy skills



(ii) 21st Century Skills B. Digital literacy skills

TASK: Answering the questions select which digital literacy skill you believe the outreach practice facilitates and explain how.

If YES, describe how the practice facilitates the skill. If NO, move to the next question.

Information Literacy – Does the practice require participants to recognize when information is needed and have the ability to locate, evaluate, and use effectively the needed information? *

- [ ] YES
- [ ] NO

If yes, please explain how?

Your answer

Media Literacy - Does the practice require participants to analyse, critically evaluate, and/or create media? *

- [ ] YES
- [ ] NO

If yes, please explain how?

Your answer

ICT (Information, Communications & Technology) literacy - Does the practice require participants to make use of ICT products that store, retrieve, manipulate, transmit or receive information electronically in a digital form, e.g. personal computers, digital television, email, robots? *

- [ ] YES
- [ ] NO

If yes, please explain how?

Your answer

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Figure 1.16 – Google Form Questionnaire Sub-Unit – Subject Matter (2. 21st Century Skills: B. <u>Digital Literacy Skills.</u>

Table 1.4 shows the responses in percentages to the digital literacy skills.

21st Century Skills B. Digital literacy skills	% Fraction Yes	% Fraction No
Information Literacy	60.86956522	39.13043478
Media Literacy	69.56521739	30.43478261
ICT Literacy	82.60869565	17.39130435

Table 1.4. Table of Evaluated Practices for 21st Century Skills B. Digital literacy skills

The graph below shows that ICT literacy is strongly represented in over 80% of the outreach practices. Media literacy is represented in almost 70% of the practices. This skill requires students to analyse, critically evaluate or create media so it is a positive to see this high level skill represented in so many practices. Information literacy is represented in 60% of the practices. This skill asks if students can recognise when information is needed and have the ability to locate, evaluate, and use effectively the needed information. This is a skill worth examining further when developing the Demonstrators.

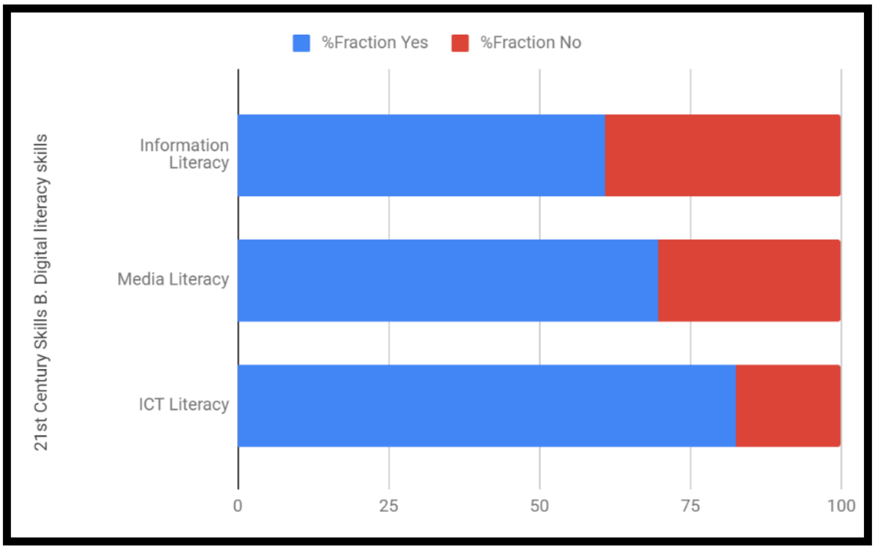
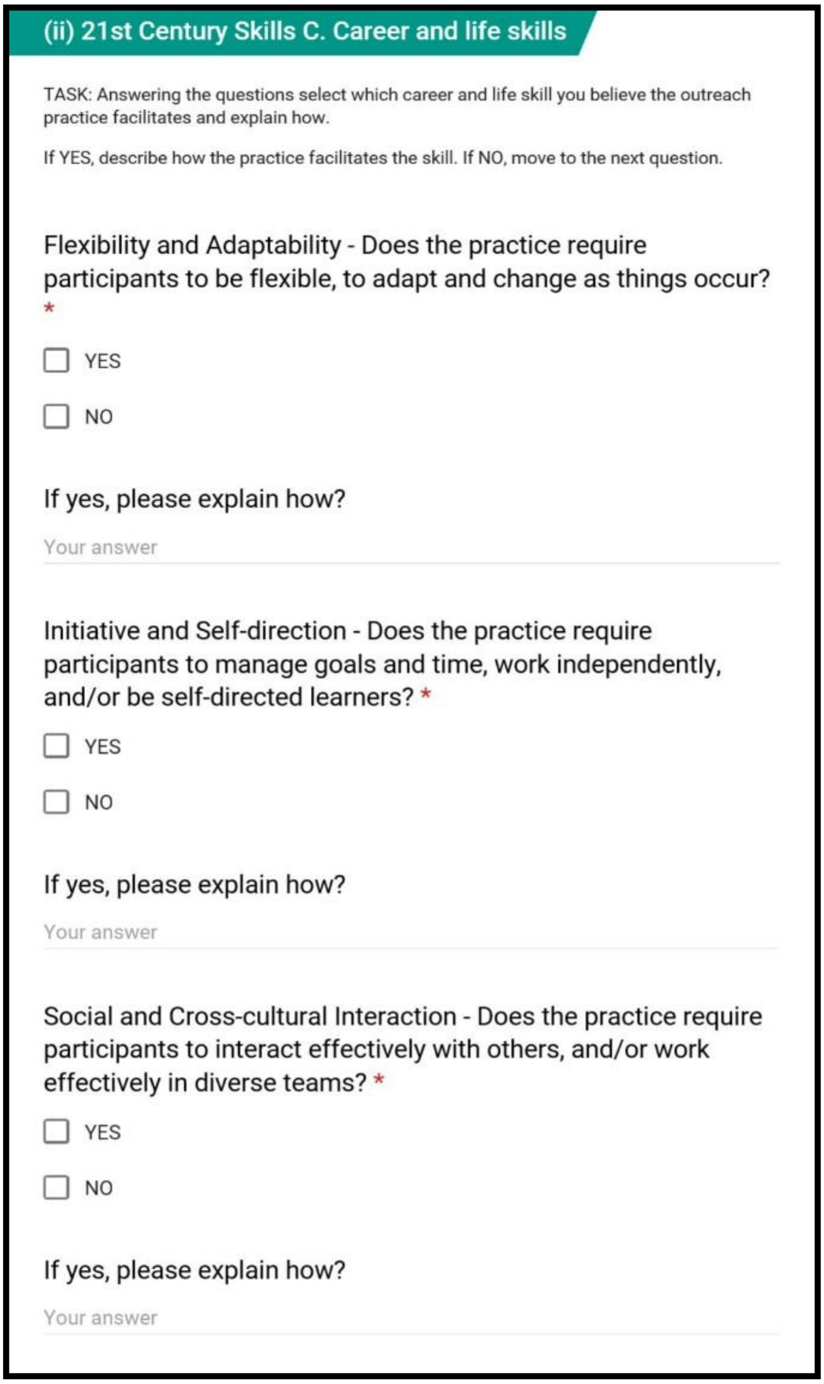


Figure 1.17 – Graphic Analysis of Evaluated Practices for 21st Century Skills B Digital literacy skills

C. Career and life skills



(ii) 21st Century Skills C. Career and life skills

TASK: Answering the questions select which career and life skill you believe the outreach practice facilitates and explain how.

If YES, describe how the practice facilitates the skill. If NO, move to the next question.

Flexibility and Adaptability - Does the practice require participants to be flexible, to adapt and change as things occur? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Initiative and Self-direction - Does the practice require participants to manage goals and time, work independently, and/or be self-directed learners? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Social and Cross-cultural Interaction - Does the practice require participants to interact effectively with others, and/or work effectively in diverse teams? *

☐ YES

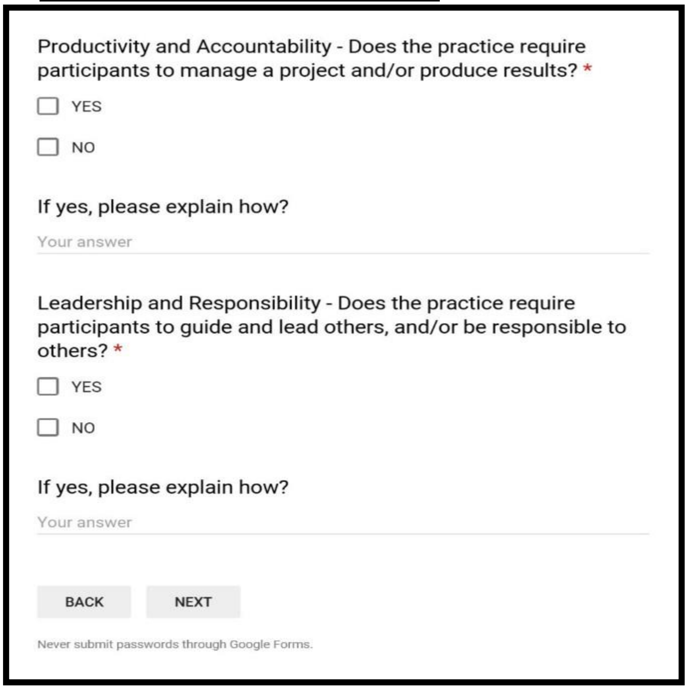
☐ NO

If yes, please explain how?

Your answer

Figure 1.18 – Google Form Questionnaire Sub-Unit – Subject Matter (2. 21st Century Skills:

C. Career and Life Skills Part 1.



Productivity and Accountability - Does the practice require participants to manage a project and/or produce results? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

Leadership and Responsibility - Does the practice require participants to guide and lead others, and/or be responsible to others? *

☐ YES

☐ NO

If yes, please explain how?

Your answer

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Figure 1.19 – Google Form Questionnaire Sub-Unit – Subject Matter (2. 21st Century Skills:

C. Career and Life Skills Part 2.

The key 21st Century Skills in career and life skills are shown in Table 1.5.

21st Century Skills C. Career and life skills	%Fraction Yes	%Fraction No
Flexibility and Adaptability	56.52173913	43.47826087
Initiative and Self-direction	82.60869565	17.39130435
Social and Cross-cultural Interaction	86.95652174	13.04347826
Productivity and Accountability	60.86956522	39.13043478
Leadership and Responsibility	26.08695652	73.91304348

Table 1.5 Table of Evaluated Practices for 21st Century Skills C Career and Life skills

It is interesting to note from the graph that initiative and self-direction and social and cross-cultural interaction are included in over 82% of the best practices. As these outreach practices are designed for use in schools across Europe and will be available to access online then this is a positive outcome. Leadership and responsibility come in at a low 26% of the practices. These are important skills for the 21st century but due to the nature of the outreach practices it may not be possible to include it in all the outreach practices.

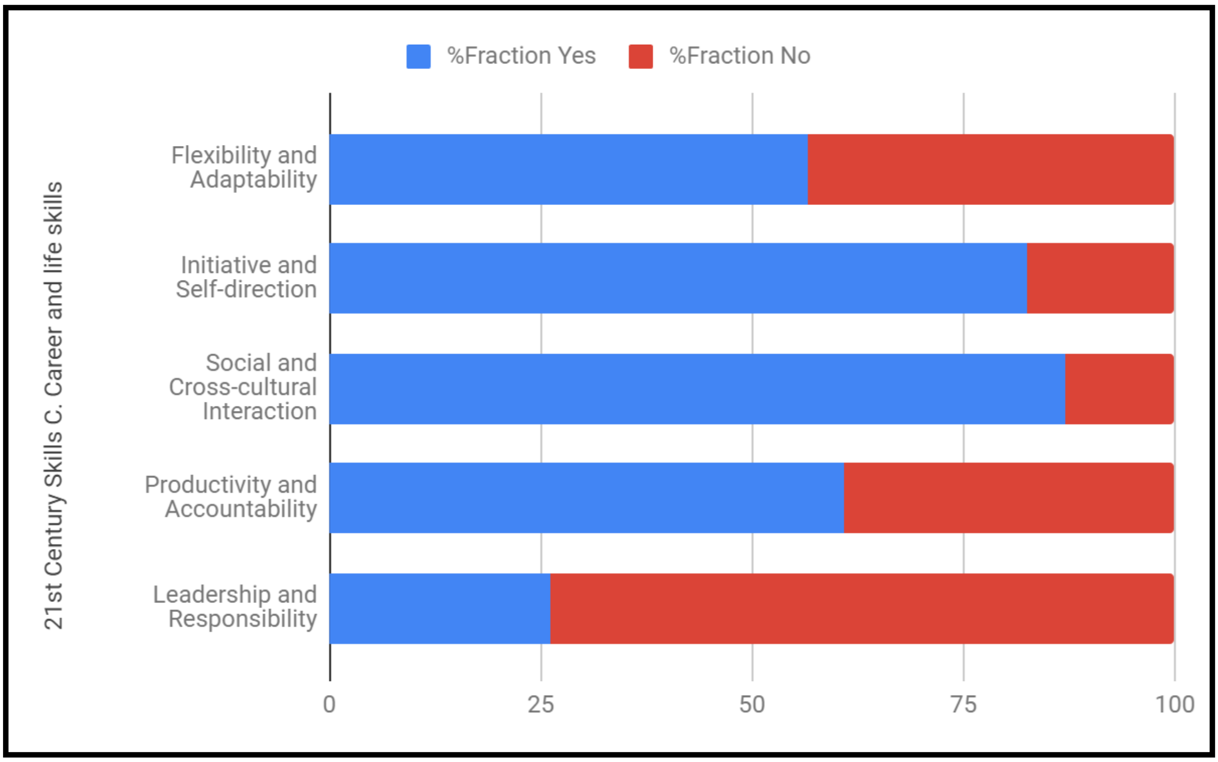


Figure 1.20 – Graphic Analysis of Evaluated Practices for 21st Century Skills A. Learning and Innovation Skills

Unit 2 Outreach Practice and Analysis of Learning

Outcomes Sub-Unit – Statements

Section C of the pedagogical framework for the selection of outreach practices focused on analysing the learning outcomes of the outreach practices in the form of statements. These statements are important as they show what a student is expected to learn and to be able to do as a result of an outreach practice. Bloom's [34] taxonomy of the cognitive domain, Simpson's [43] taxonomy of the psychomotor domain and Krathwohl et al.'s [44] taxonomy of the affective domain is useful for categorising and expressing learning outcomes into cognitive, affective and psychomotor statements:

1. Cognitive Statements deals with intellectual results, knowledge, concepts and understanding.

2. Affective statements include feeling, interest, attitudes and appreciations that may result from science instruction.
3. Psychomotor Statements includes outcomes that stress motor development, muscular coordination and physical skills.

It is worth noting that the Affective and Psychomotor domains are often forgotten about when learning outcomes are being developed so we wanted to include these domains in our analysis of the outreach practices. Adapting Bloom's [34], Simpson's [43] and Krathwohl et al.'s [44] taxonomies with descriptors and sample answers partners were asked to analysis and state their practices learning outcomes under the above statement categories.

Evaluation Task: Under the domain categories of cognitive, affective and psychomotor state the learning outcomes you expect participants to acquire as a result of the outreach practice.

Learning Outcomes are statements that define and measure the expected outcomes/intentions in terms of demonstrable skills or knowledge that will be acquired by a participant as a result of the outreach practice. They state what we want and expect a participant to learn and be able to do as a result of the outreach practice.

Outcomes & Intentions can be written as;

1. Cognitive Statements – They deal with intellectual results, knowledge, concepts and understanding.
2. Affective Statements - They include feeling, interest, attitudes and appreciations that may result from science instruction.
3. Psychomotor Statements - They include outcomes that stress motor development, muscular coordination and physical skills.

A statement for a learning outcome contains a *verb (an action)* and an object (usually a noun).

The verb generally refers to [actions associated with] the intended cognitive, affective or psychomotor process. The object generally describes the knowledge students are expected to acquire or construct. (Anderson and Krathwohl, 2001, pp. 4–5)

A general form of a statement looks like the following: Students will be able to *verb* noun phrase.
For examples:
Students will be able to *design* an experiment to test a hypothesis.
Students will be able to *distinguish* among confederal, federal, and unitary systems of government.
Students will be able to *differentiate* between rational and irrational numbers.

Figure 1.21 – Google Form Questionnaire Sub-Unit – Statements

1. Cognitive Learning Statement

Using the (i) **cognitive** descriptors below: select which categories you believe your outreach practice facilitates; and

Using a corresponding **action verb**, express the learning outcomes (verb noun statement) you expect participants to acquire as a result of the outreach practice.

N.B – It is unlikely the outreach practice will facilitate all the domain categories, just select the categories you believe the practice facilitates, and express the corresponding learning outcomes.

Cognitive Domain Statement Categories

Category	Remembering	Understanding	Applying	Analysing	Evaluating	Creating
Questions to ask yourself about your outreach practice	*Will the participant recall previously learned material?*	*Will the participant grasp meaning, explain, restate ideas?*	*Will the participant use learned material in new situations?*	*Will the participant separate material into component parts and show relationships between parts?*	*Will the participant judge the worth of material against stated criteria?*	*Will the participant put together the separate ideas to form new whole, establish new relationships?*

(i) Cognitive Domain Remembering

Examples	*Can the student RECALL information?*
Cognitive Ability	*Recall* *Recognise*
Corresponding Action Verb	**Recognising** (*identifying*) **Recalling** (*retrieving*)

Will the participant recall previously learned material ? *

- [ ] YES
- [ ] NO

If yes, express the learning outcome for the cognitive category 'remembering' (can have more than one).

Long answer text

Figure 1.22 – Google Form Questionnaire Sub-Unit – Statements 1. Cognitive Statements Part 1.

(ii) Cognitive Domain Understanding

Examples	*Can the student EXPLAIN ideas or concepts?*
Cognitive Ability	*Interpret* *Exemplify* *Classify* *Summarise* *Infer* *Compare* *Explain*
Corresponding Action Verb	**Interpreting** (*clarifying, paraphrasing, representing, translating*) **Exemplifying** (*illustrating, instantiating*) **Classifying** (*categorizing, subsuming*) **Summarizing** (*abstracting, generalizing*) **inferring** (*concluding, extrapolating, interpolating, predicting*) **comparing** (*contrasting, mapping, matching*) **explaining** (*constructing models*)

Will the participant grasp meaning, explain, restate ideas ? *

- [ ] YES
- [ ] NO

If yes, express the learning outcome for the cognitive category 'understanding' (can have more than one).

Long answer text

(iii) Cognitive Domain - Applying

Examples	*Can the student USE the new knowledge in another familiar situation?*
Cognitive Ability	*Execute* *Implement*
Corresponding Action Verb	**Executing** (*carrying out*) **Implementing** (*using*)

Will the participant use learned material in new situations? *

- [ ] YES
- [ ] NO

If yes, express the learning outcome for the cognitive category 'applying' (can have more than one).

Long answer text

Figure 1.23 – Google Form Questionnaire Sub-Unit – Statements 1. Cognitive Statements Part 2.

(iv) Cognitive Domain Analysing

Examples	*Can the student DIFFERENTIATE between and RELATE constituent parts?*
Cognitive Ability	*Differentiate* *Organise* *Attribute*
Corresponding Action Verb	**Differentiating** (*discriminating distinguishing, focusing, selecting*) **Organizing** (*finding, coherence, integrating, outlining, parsing, structuring*) **Attributing** (*deconstructing*)

Will the participant separate material into component parts and show relationships between parts ? *

☐ YES

☐ NO

If yes, express the learning outcome for the cognitive category 'analyzing' (can have more than one).

Long answer text

(v) Cognitive Domain Evaluating

Examples	*Can the student JUSTIFY an opinion, decision or course of action?*
Cognitive Ability	*Check* *Critique*
Corresponding Action Verb	**Checking** (*coordinating, detecting, monitoring, testing*) **Critiquing** (*judging*)

Will the participant judge the worth of material against stated criteria ? *

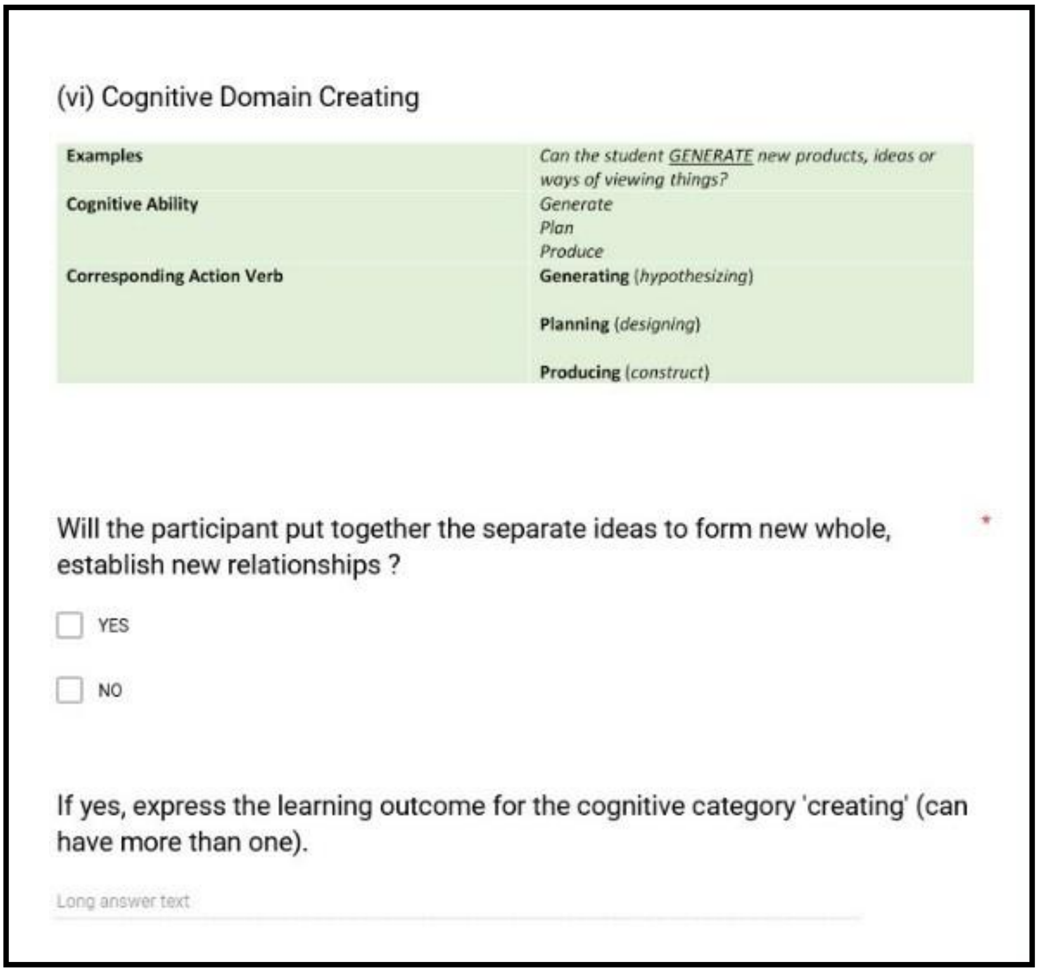
☐ YES

☐ NO

If yes, express the learning outcome for the cognitive category 'evaluating' (can have more than one).

Long answer text

Figure 1.24 – Google Form Questionnaire Sub-Unit – Statements 1. Cognitive Statements Part 3.



(vi) Cognitive Domain Creating

Examples	*Can the student GENERATE new products, ideas or ways of viewing things?*
Cognitive Ability	*Generate* *Plan* *Produce*
Corresponding Action Verb	**Generating** (*hypothesizing*) **Planning** (*designing*) **Producing** (*construct*)

Will the participant put together the separate ideas to form new whole, establish new relationships ? *

☐ YES

☐ NO

If yes, express the learning outcome for the cognitive category 'creating' (can have more than one).

Long answer text

Figure 1.25 – Google Form Questionnaire Sub-Unit – Statements 1. Cognitive Statements Part 4.

The responses to the questions relating to the Cognitive domain are outlined on Table 1.6.

Cognitive Domain	% Fraction Yes	% Fraction No
Remembering	82.60869565	17.39130435
Understanding	82.60869565	17.39130435
Applying	78.26086957	21.73913043
Analysing	60.86956522	39.13043478
Evaluating	30.43478261	69.56521739
Creating	52.17391304	47.82608696

Table 1.6 Table of Evaluated Practices for Cognitive Statement

From the graph, it is clear that all outreach practices span the different levels of the cognitive domain. 50% of the practices are in the highest level of Creating, 20% in Applying but most of the outreach practices are in the lower levels of Remembering and Understanding. This information is helpful and it is something we need to address when the partners start to create the demonstrators for Output 2.

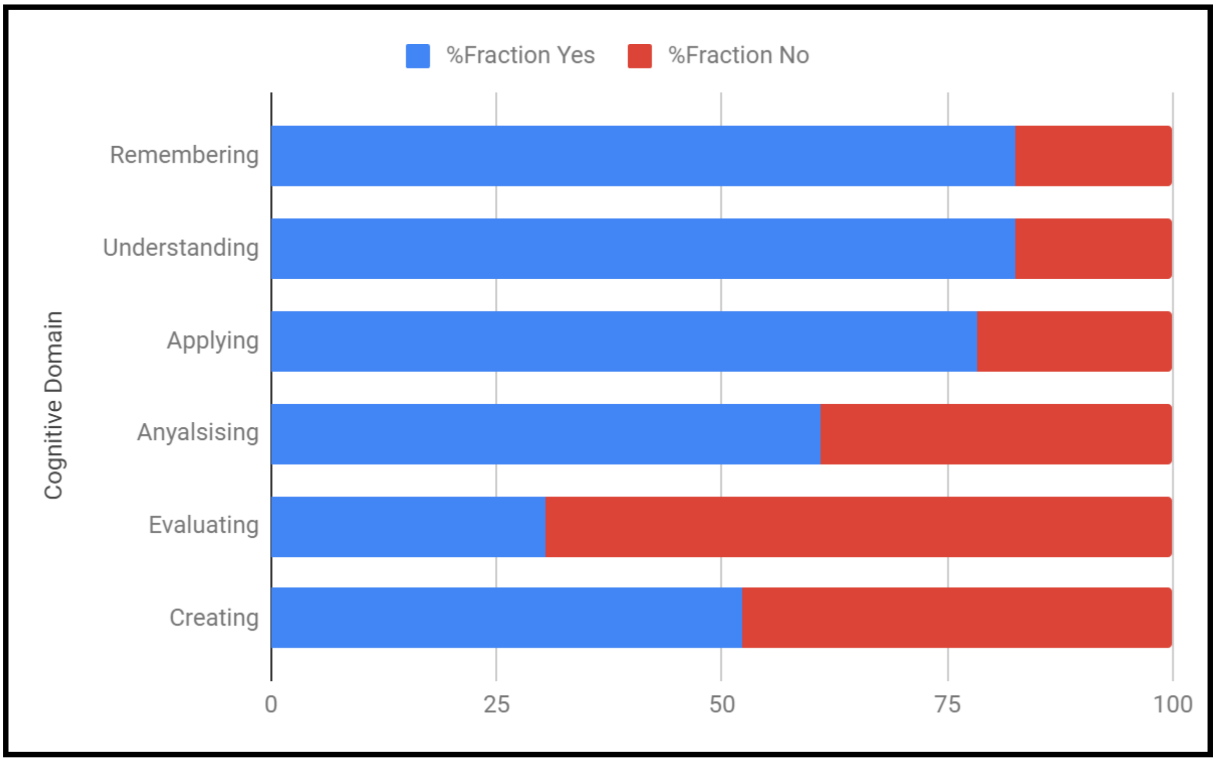


Figure 1.26 – Graphic Analysis of Evaluated Practices for Cognitive Statements

The following is a brief overview of the three domains of learning; Cognitive, Affective and Psychomotor.

Cognitive Domain. The cognitive domain involves knowledge and the development of intellectual skills. The Cognitive educational statements should be read as a scale: a gradual move towards higher-order thinking (from simple remembering through to transforming information and creating new ideas). Each level builds on and subsumes the previous levels.

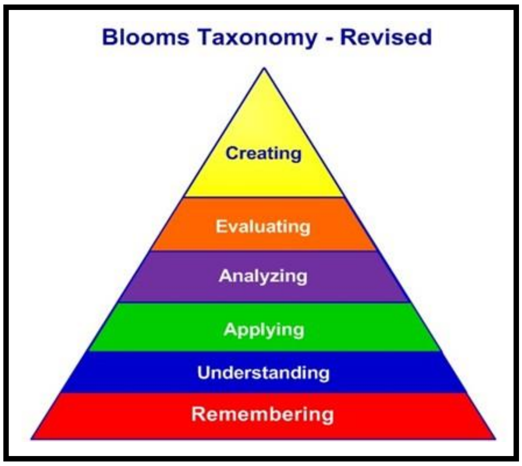


Figure 1.27. Bloom's taxonomy for the Cognitive domain

(Reproduced from http://thepeakperformancecenter.com/educational-learning/thinking/ blooms-taxonomy/blooms-taxonomy-revised/)

The analysis of the responses to the cognitive domain has already been presented in Section 1 of this document.

Affective Domain. The Affective domain refers to how we deal with issues on an emotional level, such as feelings, values, appreciations, motivation, and attitudes. This classification of affective educational statements should be read as a scale: a gradual move towards higher-order thinking (from simple events in the natural world to inquiry-based behavior). Each level builds on and subsumes the previous levels

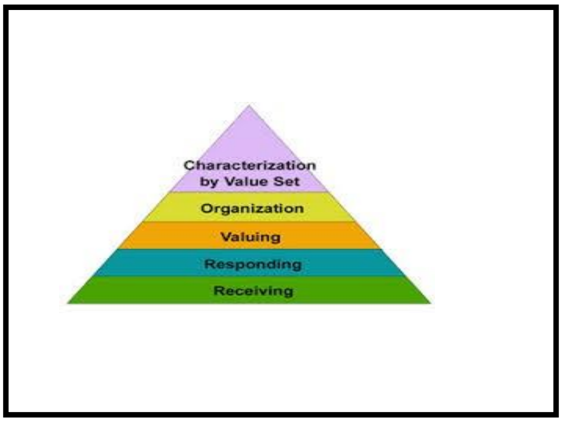


Figure 1.28. Krathwohl et al. taxonomy of the Affective domain (Reproduced from http://www.edpsycinteractive.org/topics/affect/affdom.html)

Some key findings from the responses in relation to the statements of learning in the Affective domain include:

- ☐ Realisation that learning science is beneficial
- ☐ young girls realise that science is open to all
- ☐ feel engaged by doing research with real research materials
- ☐ become more interested in science topics
- ☐ develop a keen interest in science
- ☐ motivated to work in cutting edge science topics
- ☐ independent work, motivation, proud of one's work
- ☐ co-operate with others in solving problems
- ☐ realise the importance of human activity on earth.
- ☐ understand the different applications of science in daily life
- ☐ recognise the importance of climate change
- ☐ learn how to seek knowledge and apply it to create a coherent story, following the inquiry based approach
- ☐ integrate the inquiry based approach into everyday learning experience

FRONTIERS deem the affective to be an important domain of learning and therefore will keep this to the fore in the development of the demonstrators. Collaborative and cooperative learning are included in the affective domain as is the inquiry process of formulating a question and arriving at a conclusion. Independent work and being proud of one's own work is also an important growth area in the affective domain. These affective learning outcomes are represented in the statements of learning presented above.

Psychomotor Domain. Psychomotor learning is demonstrated by physical skills, for example, coordination, dexterity, manipulation, grace, strength and speed. This classification of psychomotor educational statements should be read as a scale: a gradual move towards higher-order thinking (from simple observations to adaptation and origination behavior). Each level builds on and subsumes the previous levels.

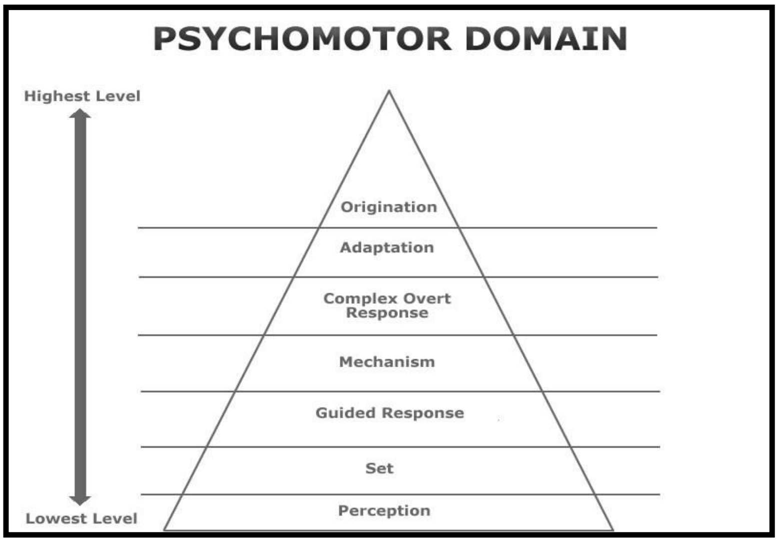


Figure 1.29. Simpson's taxonomy of the Psychomotor domain (Reproduced from http://www.geolawsdesign.com/glossary/psycho-motor-taxonomy-elizabeth-j-simpson/)

Observation is clear in the outreach practices as demonstrated in some of the key findings from the responses within the psychomotor domain.

- ☐ observe a teacher use the robotic telescope
- ☐ observe the interferometer and see how it works
- ☐ observe the use of images to extract data
- ☐ observe how gravitational waves are detected.

In relation to copying/modelling, trying a specific skill and perfecting it, the following statements were present in the outreach practices.

- ☐ copy the methods used by the teacher when using the software
- ☐ reproduce the process observed and improve on it adding more content
- ☐ make multiple simulations until they feel comfortable with the method
- ☐ adapt artistic means of expression in on or more scientific topics
- ☐ fine tune their methods until they feel positive that they have perfected them
- ☐ prepare code to solve a problem

There were fewer opportunities presented within the outreach practices for developing a new physical behavior but perhaps this can be explored further when developing the demonstrators.

Section 2 Best practices

List of Practices divided by category

2.1 Exhibitions & Events

2.1.1 Cultural Collisions

Name of Best Practice	Cultural Collisions
Context	Workshop – Event - Exhibition
Target Group	Students (High School)
Activity Setting	Research Center (informal) and Classroom(formal)
Geographical Coverage	International (5 countries so far)
Duration	1 school year
Starting Date – Ending Date	2017-
Number of teachers involved so far	100
Number of students involved so far	1,000
Organizing Institution	CERN (Initiator: Michael Hoch)
Link	http://artcms.web.cern.ch/artcms/piece_of_news/cultural-collisions-at-cern/ Full description of the activity by CERN and EA: http://portal.opendiscoveryspace.eu/en/ edu-object/cultural-collisions- demonstrator-851710 Cultural Collisions Community: http://portal.opendiscoveryspace.eu/en/community/cultural-collisions-848012 Other related activities by M. Hoch: http://mhoch.web.cern.ch/mhoch/Art@CMS/Art@CMSprojects.pdf

General Description

Introduction

Students do a full day visit at an initial arts based frontier science exhibition taking place for a week in their area. During the visit, students participate in various workshops, such as art and science workshops and others connecting science at large research infrastructures such as CERN with art and investigate the question of: What are the constituents of our world? How do we accelerate and detect elementary particles? What is CERN? What is CERN's mission? The students are accompanied by their arts and science teachers in the exhibition. The teachers also participate in the workshops as spectators and collaborate with the experts of the exhibition in order to get further insight on the topics and methodologies presented. Cultural collisions are a representative activity of the broader Art@CMS arts-based education and outreach initiative.

Practice at school

Drawing ideas from the exhibition, students initiate a school-year-long project based on one or more scientific investigations (e.g particle detection, Higgs particle and others) they can work on and perform further studies on the topic to assure sufficient content knowledge. Students will work closely with their science teacher to choose the topic of their investigation. To assure a solid content knowledge of the students, the teacher can use the support of the collaborating scientists of the Exhibition, which can be assured through virtual or live meetings, through the development of dedicated educational resources for students and others. After having decided the science topic they will pursue, students collaborate among themselves and with their arts teacher and determine the artistic methodologies (science rap, dance, flashmob, creating sculptures, drawings etc) they will implement.

The majority of the creative work is done with the arts teacher within their teaching hours (or beyond), with the support of the science teacher, due to the advantages that the arts curriculum flexibility presents. Students generate their scientifically inspired artistic intervention. The intervention might vary from a theatrical play, to an exhibit, a dance show, an artful video or something else. The arts and science teacher acts as a coach and consultant, while students take the responsibility of generating and finalizing the artistic intervention.

Students finalize their artworks and review them with their classmates and teachers making sure that they manage to convey the scientific topic in question in a coherent fashion. Students incorporate the feedback from their teachers and classmates and produce the final version of their artistic intervention. Teachers provide feedback to the students regarding the connection of their artistic interventions with the scientific topic they have chosen.

Final exhibition

Students participate in a final event taking place in their city in which they present their work and share their results with other participant schools, experts and public. The teachers support their students with the preparation and implementation of their artistic intervention. Students of different schools connect among themselves and discuss their experiences. They discuss their artistic interventions with teachers and Cultural Collisions experts and obtain feedback that will help them reflect on the topics they pursued and methodologies they followed. Teachers mediate a productive dialogue between students and between students and experts to help them obtain high quality feedback on their work.

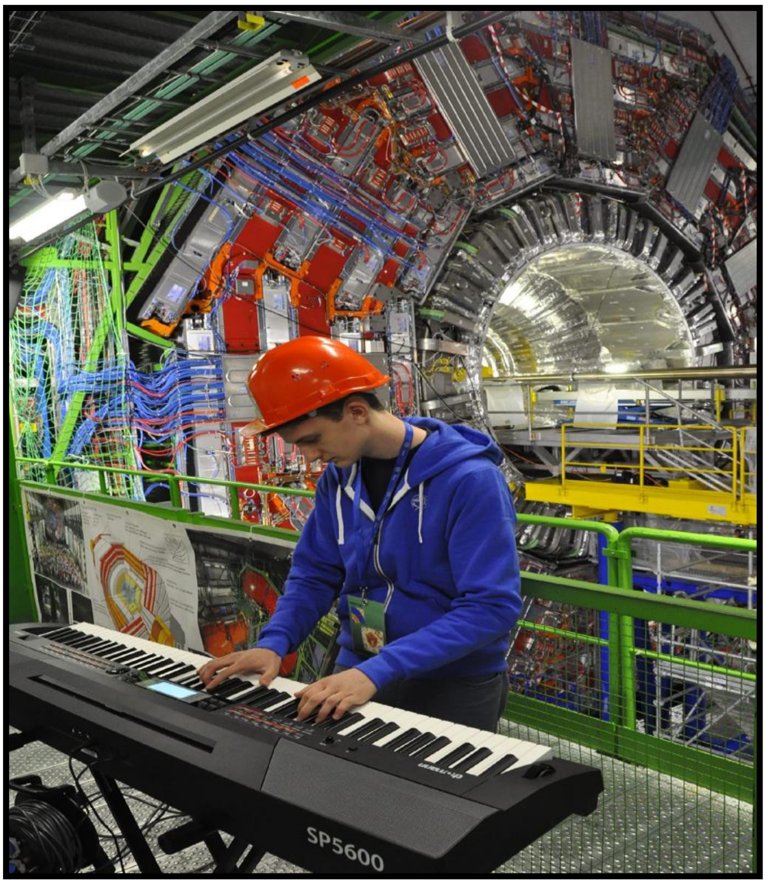
Overall Aim

Students combine science and art to learn about particle physics and CERN

Goals

1. Students learn about CERN's mission
2. Students learn about particle physics
3. Students utilize artistic representations to communicate frontier scientific concepts.
4. Students collaborate to create an arts enhanced scientific exhibit.

Photos



2.1.2 Multimessenger Control Room

Name of Best Practice	**Multi-messenger room inside Thomas Saraceno's 'On Air' exhibition**
Context	Events
Target Group	Students, General public
Activity Setting	Paris

Geographical Coverage	International
Duration	3 months
Starting Date – Ending Date	October 17th, 2018 - January 6th, 2019
Number of people involved so far	Several 1000s
Organizing Institution	EGO
Links	https://www.palaisdetokyo.com/fr/evenement/air https://wiki.virgo-gw.eu/Main/SaracenoOnAirExhibition

General Description

The 'On Air' exhibition dedicated to multi-messenger astronomy was organized at Palais de Tokyo by the Argentinian artist Tomas Saraceno. In the exhibition, that ran from October 17th, 2018 to January 6th, 2019, a multi-messenger control room where all the data coming from the participating experiments (VIRGO, KM3Net, Auger, Antares, AMS) were available to the visitors, has been setup at entrance of the exhibition. The control room is made by a set of 10 Raspberry PIs, each one connected to a monitor, showing the live data of the experiments. More details are available at https://wiki.virgo-gw.eu/Main/SaracenoOnAirExhibition

Overall Aim

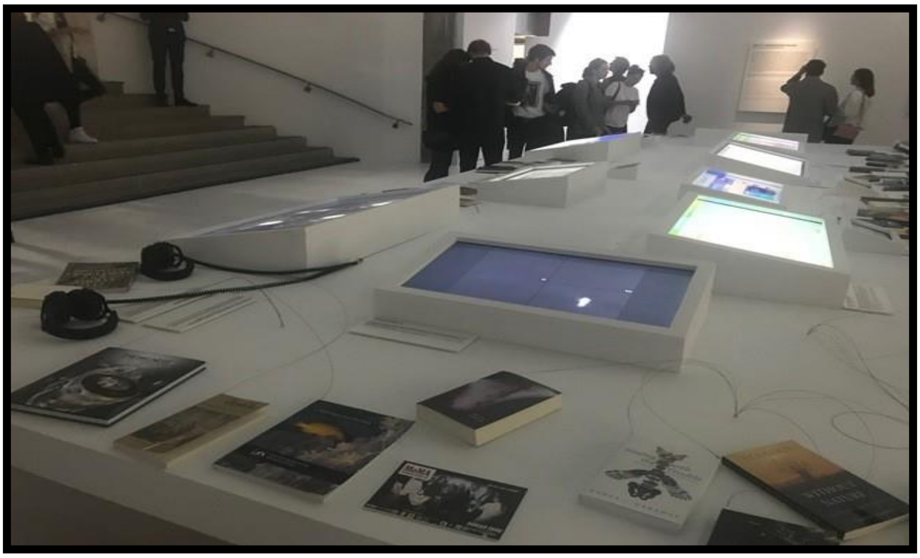
Highlight the deep connection between all arts (both performing and figurative) and science.

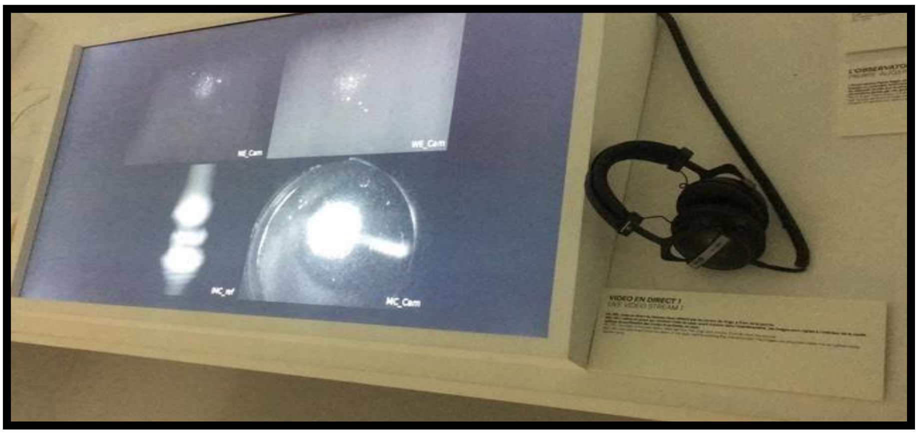
Goals

1. Generate interest and understanding of what gravitational wave detection is all about in the artists and in people interested in arts.
2. Make artists involved in our activities, making them understand the importance of fundamental research.

3. Stimulate artists to dedicate part of their work to science.
4. Make artists and the exhibition visitors understand the enormous technical and scientific challenge of gravitational wave detection.

Photos





2.1.3 Gender-equality in science

Name of Best Practice	**Women and Science**
Context	Event
Target Group	High School students
Activity Setting	At school (Liceo 'Dini' in Pisa, Italy)
Geographical Coverage	Local
Duration	2-3 hours
Starting Date – Ending Date	2018 -
Number of teachers involved so far	2
Number of students involved so far	100
Organizing Institution	EGO, Liceo 'Dini' High school
Link	http://public.virgo-gw.eu/Bright2018/ https://www.youtube.com/watch?v=1iD1BpV2_K8&t=735s

General Description

This program foresees specific gender-innovation actions in education and gravitational-wave science by creating fresh liaisons between EGO-Virgo and schools, stimulating physics interest from the earliest formative years, presenting new success stories featuring women in physics. On September 2018, during the researcher's night, EGO has organized a conference with Marica Branchesi and several key women in a high school of Pisa.

Overall Aim

This conference was given to generate the interest on science and more specifically on gravitational waves and to devise a truly innovative gender-oriented educational program.

Goals

1. to stimulate physics interest from the earliest formative years
2. to develop curricula that are gender sensitive
3. to mentor girls and young women and changing mind-sets
4. to inspire future generation of girls and boys by featuring the lives and careers of outstanding women in science.

Photos

2.1.3 The Interactive LHC Tunnel

Name of Best Practice	The interactive LHC Tunnel exhibition
Context	Touring exhibition
Target Group	Students (11-18 years old)
Activity Setting	Informal setting (science fair, science center, research center); Formal Setting (school premises)
Geographical Coverage	More than 40 sites in more than 20 countries in the EU and Asia
Duration	Visit: 1-2 school hours. Approx. availability 1 month per site.
Starting Date – Ending Date	2012-
Number of teachers involved so far	~2,000 students
Number of students involved so far	More than 1000 students per site (~40,000 students)
Organizing Institution	CERN MediaLab
Link	http://medialab.web.cern.ch/content/lhc-interactive-tunnel Full activity developed by EA can be found here: http://portal.opendiscoveryspace.eu/en/edu-object/lhc-tunnel-demonstrator-850960

General Description

The Interactive LHC tunnel is an interactive ICT-enhanced exhibit created by CERN's media-lab in order to bring students closer to the scientific endeavors taking place at the world's largest particle physics laboratory.

By having students to "kick" protons in order to produce simulated high energy

proton collisions and observe the products of them and by having students experiment and perform in a visualization of a world with and without the Higgs boson, their interest in science is sparked and the complex subatomic phenomena are addressed in a fashion
understandable by them.

This is a student activity taking place in both formal and informal settings, promoting the connection of school and research center and can take place both in local and in national level."

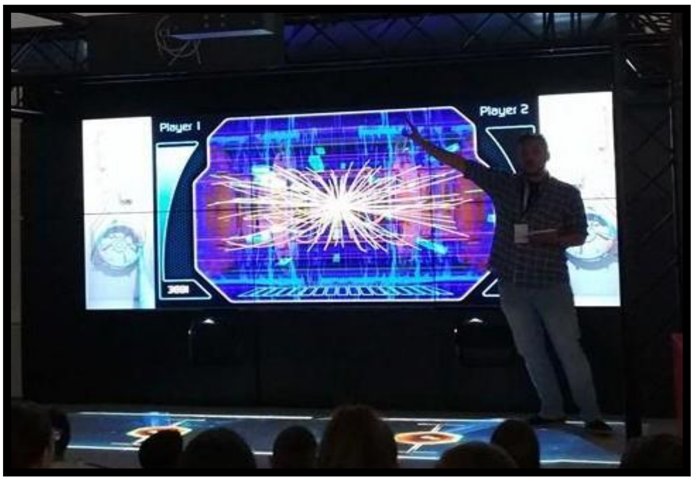
Overall Aim

Introduce Frontier Science to students using a game based approach

Goals

1. The students to understand the principles of particle acceleration, collision and detection at CERN
2. Students learn about Einstein's famous E=mc2 equation and learn that higher collision energies can result in the production of heavier particles.
3. Students learn about components of a modern particle detector including the tracker and the calorimeter and learn how these detectors can provide us with information regarding the collision process and products.
4. Students understand experientially the effect of the Higgs field on matter and understand the main difference between massive and massless particles.

Photos



2.2 Competitions

2.2.1 BeamLine 4 Schools Competition

Name of Best Practice	BeamLine 4 Schools Competition
Context	Competition
Target Group	Students 16-19 years old
Activity Setting	In school (preparation) : project or after- school hours ; Research center (execution of the winning experiments at CERN)
Geographical Coverage	International (76 countries so far)
Duration	1 September – 31 March of next year (submission)
Starting Date – Ending Date	2014 -
Number of teachers involved so far	1000
Number of students involved so far	936 teams/8500 students
Organizing Institution	CERN
Link	http://beamline-for-schools.web.cern.ch

General Description

Teams of at least 5 students 16-19 years old and at least 1 coach (1 teacher and associated researcher) from one or more schools (in the same or different countries) propose an experiment to be executed in the CERN PS T9 Beamline (2018 version takes place at DESY).

Students write a 1000 word long proposal and prepare a 1-minute long video to describe their experiment. Proposals are evaluated according to:

- The feasibility of the experiment
- The ability to follow the scientific method

- The motivation of the experiment and why you want to come to DESY
- The creativity of the experiment and the 1-minute video

The teams can communicate with the National Contacts (Scientists involved in the BL4S competition) to discuss their proposals. Proposals are selected in two stages: The short-list is selected from a pre-selection committee of volunteer experts. The final two winning teams are selected from the SPSC committee of CERN.

Two winning teams win a 10-12 trip to CERN (2019: DESY) to execute their experiments with laboratory staff scientists with all their costs covered. Shortlisted teams win other prizes (Cosmic –Pi detectors for their schools and t-shirts for all team members).

Overall Aim

This is a competition that aims to introduce and motivate high school students to particle physics .

Goals

1. Students get acquainted with particle physics
2. Students get acquainted with particle physics instrumentation: accelerators and detectors
3. Students collaborate among them, with their teachers and with researchers to create a proposal and a video.
4. Students get acquainted with the culture of large research infrastructures and with the way research is being done in them.

Photos

2.2.2 Cascade Competition

Name of Best Practice	Cascade Competitions
Context	Competition
Target Group	Students 16-18 years old
Activity Setting	In school (preparation, cascade); University (finals)
Geographical Coverage	National UK, Slovakia
Duration	~6 weeks
Starting Date – Ending Date	2006-2012
Number of teachers involved so far	N/A
Number of students involved so far	100 **schools** in UK
Organizing Institution	University of Birmingham; Sponsored by STFC
Link	https://www.birmingham.ac.uk/schools/ physics/outreach/secondary-schools/ cascade.aspx

General Description

In the UK version of the Cascade competitions, groups of A Level students were invited, with support from their teachers and particle physicists at Birmingham, to prepare a short presentation relating to particle physics, and then deliver it to another group of students, either at their own school or college, or to an invited audience from other institutions (A – Level/Y11 students, and pre-GCSE students/Y7-9). Many times, the Cascade competition was used as a follow-up of the Master classes event. Students were asked to prepare a 20 minute long Powerpoint presentation with at least 2 students per competing school. They could use also Drama, theater, demonstrations and other ways that they considered optimal during their presentation. Thematology was specified previously: Particle Accelerators, Particle Detectors, Recreating the Early Universe at the LHC and others.

After this, the students organized an event delivering the presentation to other students. After this, they sent a copy of their presentation, information about the event and optionally a video recording of their event to the competition committee. The 6 best teams were invited at the UoB for the finals before a panel of experts. The prizes were: funding for the winning teams and for the two major winners a substantial financial support in order to visit CERN.

Overall Aim

Students learn about specific topics in modern Physics and how to communicate them.

Goals

1. Students take part in a competition with specific criteria and obligations.
2. Students learn how to communicate science effectively.
3. Students collaborate.

Photos

2.2.3 Dark Skies Rangers

Name of Best Practice	Dark Skies Rangers
Context	Competition or School Project
Target Group	Students 6 - 19 years old
Activity Setting	In school (preparation) : project or after- school hours
Geographical Coverage	International
Duration	1 October – 30 April (Submission) – Results - May
Starting Date – Ending Date	2009 - ongoing
Number of teachers involved so far	Over 300
Number of students involved so far	Over 1000
Organizing Institution	NUCLIO
Link	http://dsr.nuclio.pt

General Description

Students learn about light pollution and perform audits to the streets around their school and houses. Students then create plans to overcome the light pollution problem and present them to their community. In Portugal one student created a plan to change the light bulbs of the streets and presented it to the municipality, which valued his work and proceeded with the change of the light bulbs. Every year there is a report and a drawing contest where students highlight the problem of light pollution and suggest possible solutions. Calendars made with the compilation of the drawings are then created and distributed so as to raise awareness inside the community and beyond.

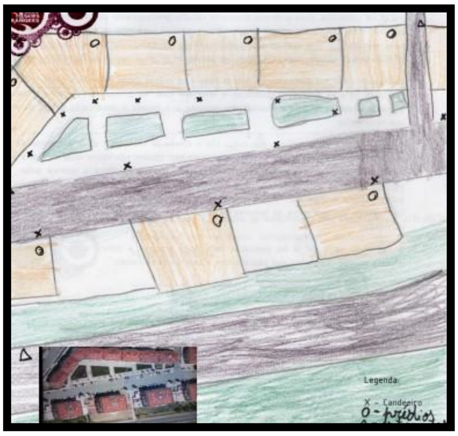
Overall Aim

This practice aims at raising awareness for the problem around light pollution, turning students into change makers in their municipalities.

Goals

1. Promote awareness about light pollution
2. Provide students with a methodology to make an effective audit to their street's lightning
3. To create enthusiasm in students toward the science fields
4. Allow students to create relevant projects for their communities
5. Engage students in awareness campaigns in their communities
6. Give students the opportunity to make the chance in their communities
7. Communicate the causes and consequences of light pollution;
8. Raise awareness of the importance of using outdoor lighting that are energy efficient and that direct the light downward;
9. Contribute to the reduction of light pollution and the preservation of the night sky;
10. Promote interest in Astronomy.

Photos



Legenda
X - Candeeiro
O - prédios

REPORTAGEM
RANGERS
Os "globos" são um péssimo exemplo, pois emitem luz para cima e para os lados e deixam a parte de baixo obscura. Impedem-nos de visualizar as estrelas
Excelente exemplo. Está à altura certa, cerca de 3,5 metros, a luminária faz um ângulo reto com o poste e ilumina só para o chão. Existe em quase todas as passadeiras, dando maior segurança aos peões no atravessamento noturno.
Qualidade dos candeeiros, do ponto de vista da poluição luminosa e da eficiência energética:
Ótimo
Bom
Mau
Péssimo
Apesar de o poste ser relativamente alto, este é um bom exemplo, a lâmpada está oculta, ilumina só para baixo e não cria obscuridade.
Além de ser muito alto, permite-nos ver a lâmpada à distância, principal sintoma de que transmite luz para o céu, produz poluição luminosa e desperdiça energia.
Este tipo de candeeiro dispersa a luz em várias direções, mesmo
Pesquisa realizada no âmbito do Programa OSOS, tendo como base as perguntas: por que é qu… mos tão poucas estrelas no céu, mesmo em noites limpas? O que é que podemos fazer para v… céu estrelado noturno? O resultado da pesquisa permitiu identificar candeeiros de rua que produzem diferentes níveis de poluição luminosa. Ao clicar nas imagens podemos ver os exemplos no Google Maps

2.2 Research Projects

2.2.1 Cosmic Rays at School

Name of Best Practice	Cosmic Rays at school	
Context	Research project	
Target Group	Upper High School	Students
Activity Setting	In and Out of school activity	
Geographical Coverage	International	
Duration	6 months - 1 year	
Starting Date - Ending Date	2003-	
Number of teachers involved so far	More than 100	
Number of students involved so far	**More than 1000**	
Organizing Institution	Centro Fermi, Rome; Hellenic Open University; NIKHEF; Fermilab; University of Birmingham; DESY; Cosmos a l'ecole	
Link	http://www.hisparc.nl/en/; https://eee.centrofermi.it/; http://www.helycon.gr/HELYCON/HELYCON_in_a_nutshell.html; http://www.sciencesalecole.org/plan-cosmos-a- lecole-materiel/	

General Description

This practice refers to the installation of cosmic ray detectors in school rooftops. Students with their teachers in collaboration with scientists assemble the detectors, are responsible for their maintenance and data acquisition and can use the acquired data to perform various studies regarding cosmic rays near the surface of the sea.

The purpose of such an activity is twofold: In research, to cover a large area with sparsely placed cosmic ray detectors in order to measure the properties of Extensive Air Showers; In education to have students participate in the scientific endeavor through the construction and maintenance of a detector, as well as through data acquisition and data analysis.

The initiative of bringing cosmic ray research in the classroom has started officially since 2003 with the EEE project in Italy and the HiSPARC project in Netherlands and has since been adopted in other countries across the world. Furthermore, schools which do not have access to a cosmic ray detector are able to use data from other educational detectors which are freely available online in order to perform their own scientific inquiries. This initiative has been met with enthusiasm and has had great success. Dedicated events such as the Muon Week or the International Cosmic Day have been organized to support and highlight the student activities in the specific subject area.

Overall Aim

Students participate in the scientific endeavor through the construction and maintenance of a cosmic ray detector, as well as through data acquisition and data analysis.

Goals

1. Students participate in the construction and assembly of a cosmic ray detector.
2. Students are empowered to gain responsibility regarding the monitoring and maintenance of the detector.
3. Students acquire real scientific data and support scientific research.
4. Students learn about cosmic ray Physics, detection, and applications.
5. Students perform their own inquiries using real data.

Photos

2.2.2 Sun 4 all

Name of Best Practice	Sun 4 all
Context	Research Project
Target Group	Students 6 - 19 years old
Activity Setting	In school (preparation) : project or after- school hours
Geographical Coverage	International
Duration	N/A
Starting Date – Ending Date	2005 – on going
Number of teachers involved so far	over 300
Number of students involved so far	Over 6000
Organizing Institution	University of Coimbra
Link	http://www.mat.uc.pt/sun4all/index.php/en/

General Description

Students use digitized images of the sun to do several activities like counting spots on several days, evaluating an 11-year cycle of the sun, making solar rotation films, correlating solar activity and solar characteristics with climate change, etc. Using

SalsaJ students can work with the images and create timeline of sun activity, etc. Students gather data and use a spreadsheet to build their graphs and to elaborate their conclusions.

Overall Aim

This practice intends to introduce students to the research process on stars. It provides a brief introduction to the stars and what we can study, image processing, photometry and the science behind observing stars. Students can also explore arts through pictures of Stars, using Salsa J to process them as they wish.

Goals

1. Notice the existence of sunspots on Sun's surface.
2. Verify that the number of detected sunspots may change throughout the Days.
3. Overlay several spectroheliograms of consecutive days to highlight Sun Rotation.
4. Figure out (in Km) the dimensions of a prominence.
5. To figure out the speed and period of Sun rotation.
6. Relate sun activity with climate change
7. Allow students to work with real research instruments
8. Allow students to independently explore science and feel engaged

Photos

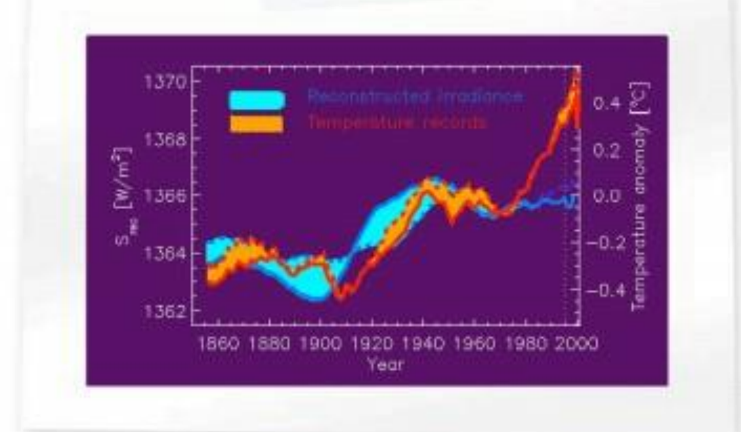


Figure 1: Solar irradiation and temperature variation since 1855 up to 2000 (source: http://www.mps.mpg.de/projects/sun-climate/resu_body.html)

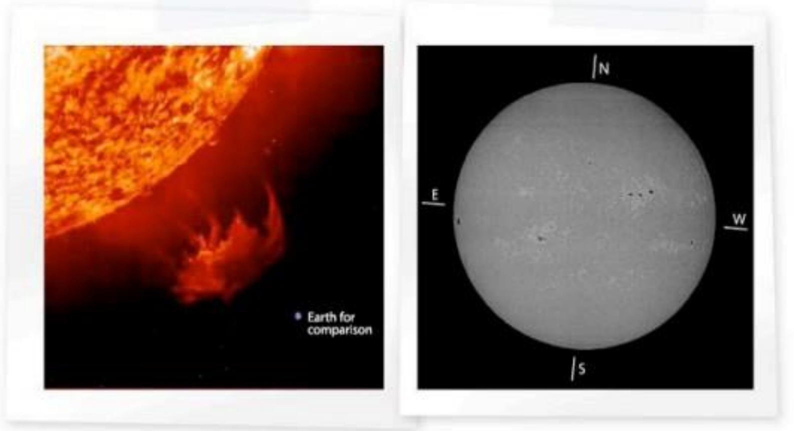


Figure 2: The left image shows a prominence and also the comparison between its size and the size of the Earth. On the right, sunspots can be observed, identified as the darker zones on the Sun's surface.
(source: SoHo, ESA and the Astronomical Observatory of the University of Coimbra)

2.2.3 Black Holes In My School (BHIMS)

Name of Best Practice	Black Holes in My School
Context	Research Project
Target Group	Students 13 - 19 years old
Activity Setting	In school (preparation) : project or after- school hours
Geographical Coverage	International
Duration	N/A
Starting Date – Ending Date	2015 - ongoing

Number of teachers involved so far	10
Number of students involved so far	300 students
Organizing Institution	NUCLIO
Link	

General Description

Students are introduced to Black Holes through a series of interactive videos that include movie scenes from "Interstellar" and "Morgan Freeman" explanations. After this, they learn how to use images taken by robotic telescopes and analyse them using a software called Sala J. Students analyse the luminosity of objects in the sky using photometrics, and then they measure the brightness of the companion star to the Black Hole Candidate XTE J1118. After this they create a graph with the values they measured and find the limit mass of the black hole candidate in this system.
After this, students are allowed to make their own observations using Faulkes Telescope.

Overall Aim

Involve students in the research process on stellar mass black hole candidates, learning about theory of Black Holes, image processing, photometry and the science behind observing black hole candidates.

Goals

1. Learn Black Hole physics in class
2. Explore about stellar black hole candidates.
3. Observe by using robotic telescopes.
4. Understand the principles of photometry.
5. Determine the mass limits of a compact object in a binary system.
6. Allow students to independently explore science and feel engaged

2.2.4 Radio Astronomy

Name of Best Practice	Radioastronomy
Context	School activity + outreach
Target Group	Students 10 - 19 years old
Activity Setting	In school
Geographical Coverage	International
Duration Starting Date – Ending Date Number of teachers involved so far (Portugal only)	N/A before 2011 - ongoing ~15
Number of students involved so far	~300
Organizing Institution	EUHOU /Teachers
Link	http://www.euhou.net/index.php/ exercises-mainmenu-13/radio

General Description

Student use EU-HOU radio telescopes to understand the behavior of our galaxy, the variation of the H density on it, and the speed of rotation of the Milky Way arms. Students may also find the galaxy mass to better understand the Dark Matter concept.

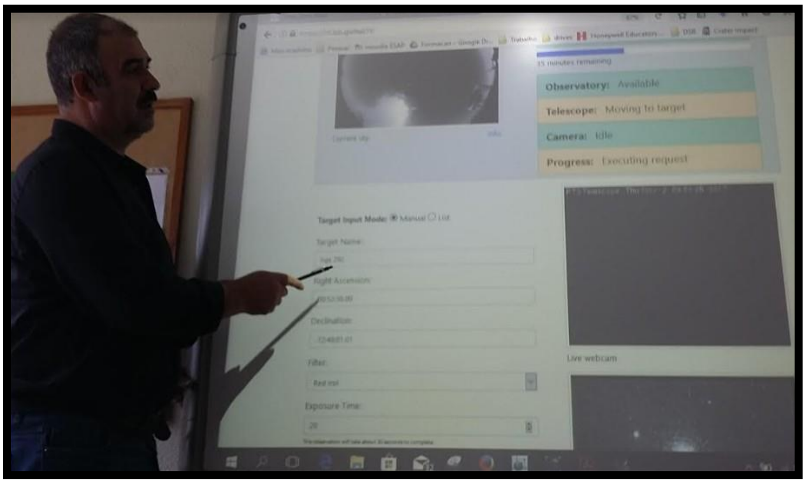
Overall Aim

Put students in contact with real science methods in class and relating their work to daily lives while learning about important physics concepts and contemporary science research

Goals

1. To motivate students to Science in an interdisciplinary way;
2. To verify scientific concepts in vogue;
3. To increase skills to work in Science;
4. Acquisition of scientific and technological competences;
5. To allow students to discover the wonder of contemporary physics research.

Photos



2.2.5 IASC - International Astronomic Search Collaboration

Name of Best Practice	**International Astronomical Search Collaboration**
Context	Research Project
Target Group	Students 13 - 19 years old
Activity Setting	In school (preparation) : project or after- school hours
Geographical Coverage	International
Duration	September - June
Starting Date – Ending Date	2007 - ongoing
Number of teachers involved so far	Over 100
Number of students involved so far	Over 1000
Organizing Institution	NUCLIO
Link	http://iasc.hsutx.edu/

General Description

The IASC promotes the International Asteroid Search Campaign where students receive, during a period of 4 weeks, images of the night sky taken by potent telescopes and use a software called Astrometrica (http://iasc.hsutx.edu/ Astrometrica.html) to analyse the images and discover Asteroids. The teachers have a guiding role, while the students make their own analysis and explorations. If a student or group of students discover an asteroid, it is considered a preliminary discovery and they are considered the "discoverers". If the asteroid is detected a second time, the discovery is considered a "provisional discovery". From there the asteroid is observed until its trajectory is determined and then the discoverers are invited to name it. In 2018 in Portugal a group of students was invited to name the asteroid they discovered. They named it "Lusitanos". After the campaign ends (4 weeks), a report is sent to the coordinator of the project: Patrick Miller from Hardin- Simmons University in Texas and the teachers and students receive a certificate.This process could be included in Frontiers as a demonstrator.

Overall Aim

Students learn about asteroids and their detection while using images taken by real telescopes, following a real scientific process and making a true contributing to the scientific research field.

Goals

1. Teach students about asteroids and different objects in the sky
2. Show to students how real science works
3. Promote interest and engagement of students in science disciplines

2.3 Exercises

2.3.1 Ice Cube Master classes

Name of Best Practice	IceCube Masterclasses
Context	Exercise
Target Group	Upper High School Students
Activity Setting	Out of school activity (visit in research centre)

Geographical	Internation
Duratio	1
Starting Date – Ending	2014
Number of teachers involved	More than
Number of students involved	More than
Organizing	University of Wisconsin
Lin	https://masterclass.icecube.wisc

General Description

The IceCube master classes provide upper high school students with the opportunity to become “IceCube scientists” for a day. Students visit a research center affiliated with the IceCube experiment for the detection of cosmic Neutrinos in ice, attend lectures and analyze real IceCube data. By the end of their analysis, students discuss with their teachers and their mentors and they connect online with other research centers in order to discuss with other students about their results.

This practice has been active since 2014 and follows the paradigm of the successful Particle Physics Master classes.

Overall Aim

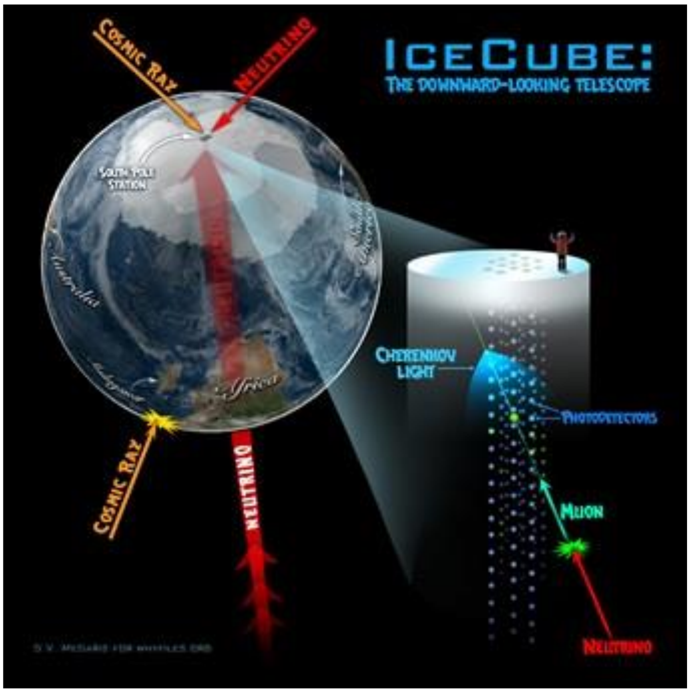
The overall aim of the IceCube master classes is to show to students how a scientist works and have them participate in a simplified analysis using IceCube neutrino and cosmic ray data.

Goals

1. Students interact with scientists and gain an authentic experience in research.

2. Students get introduced to neutrino astronomy and neutrino detection using neutrino telescopes.
3. Students analyze real data and get acquainted with the work done by scientists in this field.
4. Students collaborate to finalize their analyses and communicate with other students across the world to share their results.

Photos



2.3.2 International Master classes

Name of Best Practice	International Physics Master classes
Context	Exercise
Target Group	Students 15-19 years old
Activity Setting	In school/science center/university : Lectures (class), event analysis (computer lab), videoconference (class)
Geographical Coverage	International (52 countries in 2018)
Duration	March –April (one day events)
Starting Date – Ending Date	2004 -
Number of teachers involved so far	N/A
Number of students involved so far	13.000 last year
Organizing Institution	IPPOG
Link	http://physicsmasterclasses.org/

General Description

Each year more than 13.000 high school students in 52 countries come to one of about 215 nearby universities or research centres for one whole day in order to unravel the mysteries of particle physics. Lectures from active scientists give insight in topics and methods of basic research at the foundations of matter and forces, enabling the students to perform measurements on real data from the large experiments done at CERN at the LHC. At the end of each day, like in an international research collaboration, the participants join in a video conference for discussion and combination of their results.

Overall Aim

Show the students how a researcher works and allow them to perform a simplified but still accurate search for “new” particles.

Goals

1. Stimulate student interest in physics in general and particle physics in particular. Show the students how physics has advanced beyond what they learn at school and possibly motivate them to pursue a career in science. At the same time inform teachers about the latest developments in basic research so they would be more qualified to answer questions.
2. Students become familiar with cutting edge research done at CERN and practice a simplified version of their actual researcher work using real data collected at CERN’s accelerators. This aims to show how cutting edge research is performed and to let the students try to perform it for a short time.
3. Students collaborate with each other to achieve the best results. This shows how collaboration is essential in today’s large-scale research activities.
4. The students compare their results with groups from other countries and attempt to explain their findings. Students learn that it’s not enough to perform a measurement but apply critical thinking as well and be able to explain their findings and justify any unexpected results.

2.3.3 Mini Master classes

Name of Best Practice	Mini Particle Physics Master classes
Context	Exercise
Target Group	Students 12-17 years old
Activity Setting	In school : Lectures (class) and event analysis (computer lab)
Geographical Coverage	Local, Virtual visit to a CERN experiment

Duration	1-5 hours
Starting Date – Ending Date	No fixed dates
Number of teachers involved so far	300+
Number of students involved so far	2000+ Data from : 600 teams / 1200 students
Organizing Institution	IASA
Link	http://hypatia.iasa.gr/

General Description

Students are introduced to the world of high-energy physics and the work being done at CERN. They get the chance to learn about the new discoveries of physics in that field and talk with CERN researchers about their work and their lives there. They also get a taste of what it's like to be an actual physicist searching for new particles in the laboratory exercise with HYPATIA.

The students came to the school with their teachers and get the chance to perform hands-on exercises processing data from the ATLAS experiment at CERN. They are first introduced to the physics of the ATLAS experiment. If possible, a live connection with the Control Center of the ATLAS experiment (or another LHC experiment) gives them the chance to get acquainted with the instrumentation used in the experiment and ask questions to the scientists at CERN. Finally, a detailed introduction to the HYPATIA software is provided, after which the hands-on exercise for the rediscovery of the Z boson and the Higgs boson take place. The students also answer eight PSQ questions and their performance with the HYPATIA analysis is monitored by several indexes in order to validate step by step the education value of the good practice. At the end of the activity the students get together and discuss the results of their research.

Overall Aim

Show the students how a researcher works and allow them to perform a simplified but still accurate search for "new" particles.

Goals

1. Stimulate student interest in physics in general and particle physics in particular. Show the students how physics has advanced beyond what they learn at school and possibly motivate them to pursue a career in science. At the same time inform teachers about the latest developments in basic research so they would be more qualified to answer questions.
2. Students become familiar with cutting edge research done at CERN and practice a simplified version of their actual researcher work using real data collected at CERN's accelerators. This aims to show how cutting edge research is performed and to let the students try to perform it for a short time.
3. Students collaborate with each other to achieve the best results. This shows how collaboration is essential in today's large-scale research activities.
4. The students compare their results with groups from other countries and attempt to explain their findings. Students learn that it's not enough to perform a measurement but apply critical thinking as well and be able to explain their findings and justify any unexpected results.

2.3.4 Worldwide Data Day

Name of Best Practice	World Wide Data Day
Context	Exercise
Target Group	Students 12-16 years old
Activity Setting	In school: Lectures (class) and event analysis (computer lab), 24 h video connection with schools from all over the world
Geographical Coverage	International
Duration	2 hours analysis of events, 1/2 hour video conference on each site, the video conference for all lasts 24h

Starting Date – Ending Date	2016 -
Number of teachers involved so far	50+
Number of students involved so far	600+ students
Organizing Institution	QuarkNET
Link	https://quarknet.org/content/lhc-world- wide-data-day-2018

General Description

LHC World Wide Data Day is a 24-hour span, midnight-to-midnight UTC, in which students from around the world can analyze data from the Large Hadron Collider and share results via an ongoing, 24-hour video conference with physicist moderators taking shifts in locations around the world.

LHC-W2D2 is open to groups of 4 or more high school students who have the aptitude and interest to analyze data from the Large Hadron Collider. Each groups is encouraged but do not required to work with a sponsoring teacher. Groups of university undergraduate (or equivalent) students may also participate.

All analyses are of open, public data from the Large Hadron Collider. After data analysis, each group uploads its results at least 30 minutes before the pre-assigned time of their videoconference. Videoconferences are on Vidyo (CERN's free downloadable system); they are up to 30 minutes long and consist of up to 5 groups plus moderators. Each group has 3 minutes to present results. If there is open time after the presentations and question period, students may stay to chat with the moderators and each other.

Overall Aim

The goal is to familiarize students with one of the large physics experiments of CERN or FermiLab and stimulate their interest in physics

Goals

1. Stimulate student interest in physics in general and particle physics in particular. Show the students how physics has advanced beyond what they learn at school and possibly motivate them to pursue a career in science.
2. Students become familiar with cutting edge research done at CERN and use real data collected at CERN's accelerators to perform a simple analysis.
3. Students collaborate with each other to achieve the best results. This shows how collaboration is essential in today's large-scale research activities.
4. The students compare their results with groups from all around the world and attempt to explain their findings. Students learn that it's not enough to perform a measurement but apply critical thinking as well and be able to explain their findings and justify any unexpected results.

2.4 Citizen Science

2.4.1 Gravity Spy

Name of Best Practice	Gravity Spy
Context	Citizen Science Project
Target Group	Citizens of all ages
Activity Setting	Out of school activity
Geographical Coverage	International
Duration	Could last from 1 hr to 1 year, depending on the availability of the user
Starting Date – Ending Date	2016-
Number of teachers involved so far	Thousands of volunteers

General Description

Gravity Spy is a citizen science project initiated by the LIGO collaboration. This project aims to bring Gravitational Wave Physics closer to citizens by inviting them to help in the classification of noise sources in the detector.

Participating citizens receive online training through the Gravity Spy platform and they are called to classify images depicting detector 'noise'. They look at real LIGO data in search of 'glitches', unwanted hiccups in the signal that can sometimes be confused for or mask out gravitational waves. Glitches make finding the real thing even more difficult than it already is. Identifying the different kinds of glitches that appear in the interferometer data is crucial for LIGO and VIRGO scientists to be able to distinguish between annoying blips and signals from space.

So far more than 10000 volunteers have participated and conducted more than 1000000 classifications.

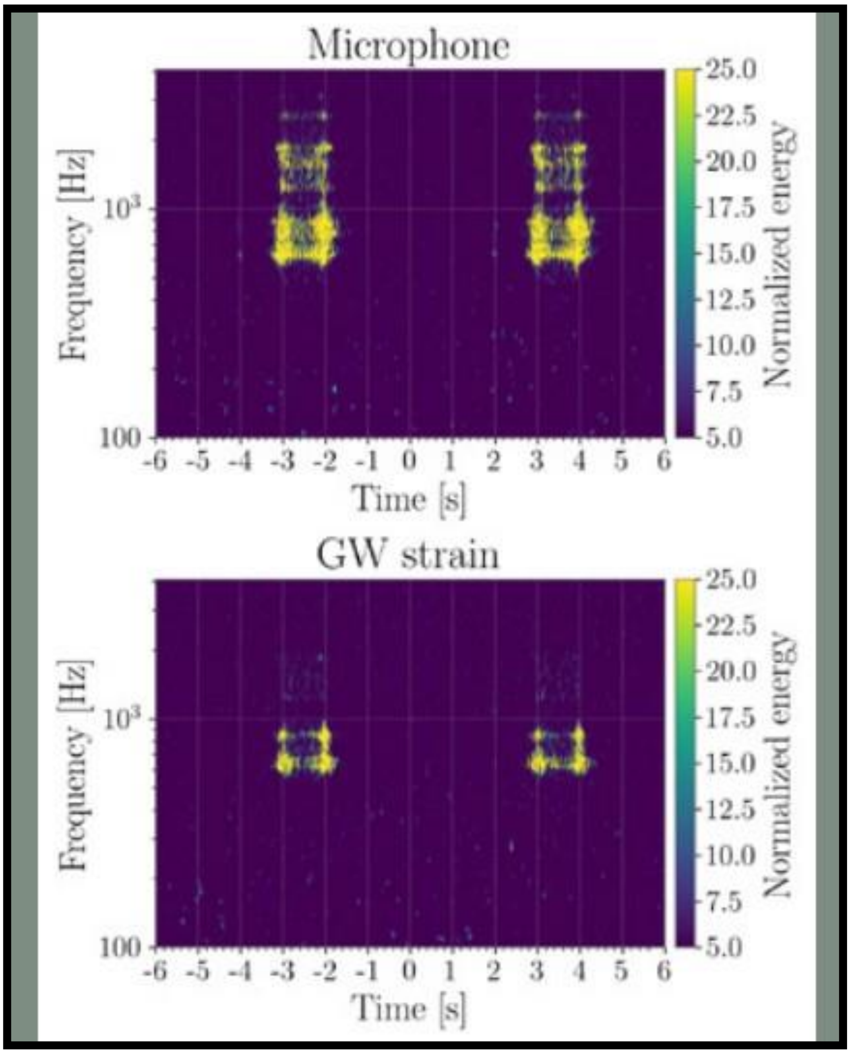
Overall Aim

The overall aim of Gravity Spy is to bring Gravitational Wave Physics closer to citizens by inviting them to help in the classification of noise sources in the detector.

Goals

1. Introduce citizens to gravitational wave astronomy
2. Introduce citizens to gravitational wave detection techniques
3. Collaborate with citizens to identify noise signatures in the LIGO and VIRGO detectors
4. Use citizen classified data to train the machine learning algorithms of the VIRGO and LIGO collaboration

Photos



2.4.2 Muon Hunter

Name of Best Practice	Gravity Spy
Context	Citizen Science Project
Target	Citizens of all ages
Activity Setting	Out of school activity

Geographical	International
Duration	Could last from 1 hr to 1 year, depending on the availability
Number of teachers involved	Thousands of
Number of students involved	5000
Organizing	VERITAS
Link	https://www.zooniverse.org/pro

General Description

Muon Hunter is a citizen science project initiated by the VERITAS collaboration in the framework of the ASTERICS EU funded project. Muon hunter utilizes data from the VERITAS gamma ray air Cherenkov telescope in order to identify "rings" which correspond to the Cherenkov radiation emitted by atmospheric muons. The VERITAS telescope aims to measure GeV gamma rays from the cosmos. In order to reduce the background of atmospheric muons they employ pattern recognition algorithms that recognize the fingerprint of these muons in the VERITAS detector. Citizens are invited to help with this classification and distinguish muon signatures in the batch of VERITAS data available. So far more than 5000 volunteers have participated and carried out more than 2000000 classifications.

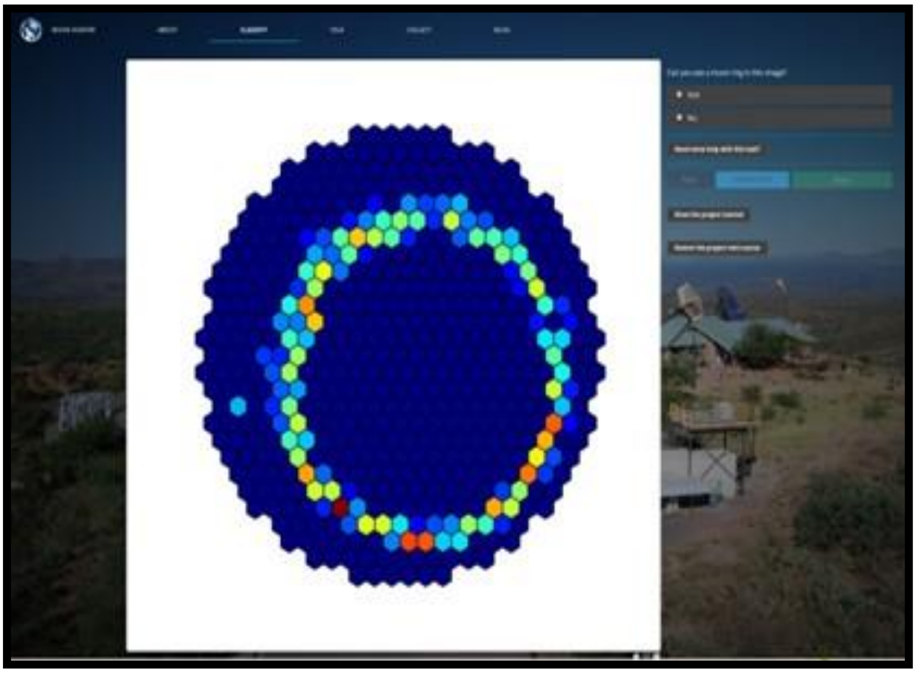
Overall Aim

The overall aim of the "Muon Hunters" best practice is to introduce citizens in the scientific endeavour by having them classify Cherenkov rings from muons.

Goals

1. Introduce citizens in the essentials for detection of atmospheric muons using the air cherenkov technique.
2. Use citizen classified data to train the machine learning algorithms of the VERITAS collaboration.
3. Introduce citizens to Astroparticle Physics.
4. Introduce citizens to noise suppression techniques.

Photos



2.5 Visits

2.5.1 Virgo site visits

Name of Best Practice	Site Visits
Context	Activity
Target Group	Students (High School, University), General public

Activity Setting	On site
Geographical Coverage	International (EU, USA, Asia)
Duration	2-3 hours
Starting Date – Ending Date	2005 -
Number of people involved so far	>10000: 1200 (2015), 2000 (2016), 4000 (2017), 4000 (2018)
Organizing Institution	EGO
Link	http://public.virgo-gw.eu/visit/

General Description

Starting from 2005, EGO started to open its doors to the schools, universities and general public. The visit consists in a 45-minute seminar about GWs and Virgo and a tour of the facility (Control Room, Experimental Buildings, Vacuum Pipes).

Overall Aim

Generate interest and understanding of what gravitational wave detection is all about.

Goals

1. To motivate students to dedicate their career to science, by transmitting excitement and enthusiasm.
2. Make general public involved in our activities, making them understand the importance of fundamental research.
3. Make general public aware of the basic concepts of General Relativity and Gravitation.
4. Make general public understand the enormous technical and scientific challenge of gravitational wave detection.

Photos

2.5.2 Virtual Visits to LHC experiments

Name of Best Practice	Virtual Visits to LHC Experiments
Context	Videoconference
Target Group	High School Students

Activity Setting	Classroom
Geographical Coverage	Around the Globe
Duration	1 hour
Starting Date – Ending Date	2010
Number of teachers involved so far	1000+
Number of students involved so far	40000+
Organizing Institution	Groups participating in the LHC experiments
Link	https://atlasvirtualvisit.web.cern.ch/ https://cms.cern/interact-with-cms/ virtual-visits

General Description

Using web-based video conferencing tools, students talk with an ATLAS (or other LHC experiment) physicist in their native language, receive a tour of the control room and get answers to their questions. If the LHC tunnel is open for repairs/upgrade (which is true now during the LHC shutdown which will last about two years) then the students get a tour of the detector and its different parts.

The goal of this practice is to familiarize the students with the corresponding LHC experiment, show them how physicists work, either in the control room or on maintaining the detector itself and also get to know one of the people working there without having to leave their school class.

Overall Aim

The students can see as much of the visited experiment as possible. If it is not running it is possible to see the experiment itself. Otherwise they can see the control room. They also get to talk to one of the resident scientists about diverse subjects including the experiment operation, everyday life, educational requirements to work there etc.

Goals

1. Show the students what a real cutting edge scientific experiment looks like. If possible the students get a look at the actual detector. Otherwise they can see the control room during the experiment operation when different groups of specialists participate in shift work in order to collect high quality data.
2. Talk to a researcher working on the experiment. Discussion can include topics on physics, everyday life, research opportunities etc.
3. Students learn about the operation of the specific experiment. How it was build, how it functions and what are the results from its operation. Even if the LHC cavern is not open, they can see the detector through underground camera projections on the walls of the control room.
4. Students get familiar with a large-scale experiment and can see how modern physics discoveries are made. This aims to provide motivation for them towards a possible scientific career. It also motivates teachers to organize visits of their classes to CERN.

2.6 Training

2.6.1 Code Week Workshops - The story of coding and coding exercises for high school students

Name of Best Practice	**Coding Week**
Context	Training
Target Group	Students (Middle Schools, 12-14 yo)
Activity Setting	On site
Geographical Coverage	Local (Tuscany)
Duration	8 hours (4 hr/day)

Starting Date – Ending Date	2016 -
Number of students involved so far	150
Organizing Institution	EU, EGO
Link	https://codeweek.eu/

General Description

As part of the international Code Week initiative, EGO, in collaboration with EURid (https://eurid.eu/en), has, for the last 3 years, provided hands-on coding experiences for 2nd-year students from the local Vincenzo Galilei middle school (http://www.icvgalileipisa.gov.it/).

Students are divided into 2 separate groups, with each of the groups visiting the EGO site on a different day of the same week.

The students follow a lecture on a specific theme. Up to now, themes have included: the growth of the Internet as a global phenomenon and its arrival in Italy; and a history of computer programming.

Subsequent to the introductory lecture, the students are divided down into 3 separate groups. Each group then participates in sessions dedicated to the use of the MIT-developed Scratch programming language. During these sessions, they complete challenges and develop their own games, all under the tutelage of members of the EGO IT Department, who are available to help students understand how the concepts they are learning translate into the real world and, specifically, into the world of gravitational-wave science.

Students are especially encouraged to frame the ideas they are learning in the context of Virgo, thinking specifically in how they are used in terms of interferometer control, monitoring and data analysis and transfer.

These sessions are interspersed with guided visits to the experimental areas of the site, which are then reinforced by a presentation dedicated to gravitational-wave science and discoveries, given by a Virgo physicist.

Overall, sessions last for an entire morning and are completed with a question-and-answer session relating to Internet safety and domain-registration handling, followed by a buffet lunch during which students can ask questions from the tutors and guides involved in the activity.

Overall Aim

The practice aims to encourage young people to take an interest in computer science and, in particular, to better understand computer programming. It aims to put these elements within the specific frame of reference of gravitational-wave science.

Goals

1. To teach students the fundamental concepts of computer programming.
2. To improve understanding of computer science in general.
3. To provide a clearer understanding of how these concepts are used within Virgo.
4. To improve the capacity of students to understand Internet safety.
5. To explain Virgo in a straightforward and understandable, but not condescending manner.
6. To show how technological concepts familiar in everyday life are also applicable to the life and working of the interferometer.
7. To assist in the development of a more general, wider knowledge relating to computer science and its evolution.

Photos

2.6.2 QuarkNET

Name of Best Practice	QuarkNET
Context	Teacher Network
Target Group	Students, Teachers, Science Centers

Activity Setting	QuarkNET centers
Geographical Coverage	US
Duration	
Starting Date – Ending Date	1999 -
Number of teachers involved so far	700+
Number of students involved so far	100,000
Organizing Institution	QuarkNET
Link	https://quarknet.org/content/home-page

General Description

QuarkNet is a long-term, research-based teacher professional development program in the United States jointly funded by the National Science Foundation and the US Department of Energy. Since 1999, QuarkNet has established centers at universities and national laboratories conducting research in particle physics (also called high-energy physics) across the United States. Mentor physicists and physics teachers collaborate to bring cutting-edge physics to high school classrooms. QuarkNet offers research experiences for teachers and students, teacher workshops and sustained follow-on support. Through these activities, teachers enhance their knowledge and understanding of scientific research and transfer this experience to their classrooms, engaging students in both the substance and processes of contemporary physics research. Teachers may receive academic credit for their participation. QuarkNet programs are designed and conducted according to “best practices” described in the National Research Council National Science Education Standards report (1995) and support the Next Generation Science Standards (2103). The program is based on a “cascade” educational system for teachers. Those who follow the course become “ambassadors” and train other fellow teachers.

Overall Aim

QuarkNet offers students and teachers the opportunity to learn about cutting edge research and new teaching methods respectively. It aims to create a mentoring network of teachers that transfers this knowledge to as many classrooms as possible.

Goals

1. Teachers learn new teaching methods and gain new understanding of cutting edge scientific methods. They can then demonstrate this kind of research to their students. Furthermore, the teachers have a "portfolio" of experiments/ exercises in their disposal and can choose the ones, which suit best their students.
2. Students learn about modern physics, perform interesting experiments and gain motivation to engage in science at school or possibly in their future studies.
3. Teachers gain knowledge and academic credit that may help advance their career.
4. After participating in the program, teachers can become educators of their colleagues. This multiplies the reach of the initiative and by establishing a "cascade" educational system reaches a lot more teachers than it would be possible to otherwise.

2.7 Activities

2.7.1 Bosemon - Learning particle physics through a card game

Name of Best Practice	Bosemon
Context	School activity + outreach
Target Group	Students 10 - 19 years old
Activity Setting	In school

Geographical Coverage	International
Duration	N/A
Starting Date – Ending Date	2012-ongoing
Number of teachers involved so far (Portugal only)	~15
Number of students involved so far	~300
Organizing Institution	7 physics teachers including one member of NUCLIO
Link	https://sites.google.com/site/bosemongame/home

General Description

Bosemon is a game that resembles 'go fish' and 'pokemon'. Students have to collect cards and make combinations to make interactions to create new particles. This game can be transformed into a demonstrator using gamification to learn particle physics.

1. Students receive some of the cards a few days in advance. Cards will have basic characteristics and interactions:
2. Students classify the cards individually based on characteristics
3. The day of the game, students group together to compare classifications.
4. Students will then play the game in a similar manner to Pokemon and fish game where they will use the interactions and characteristics to create other particles

Overall Aim

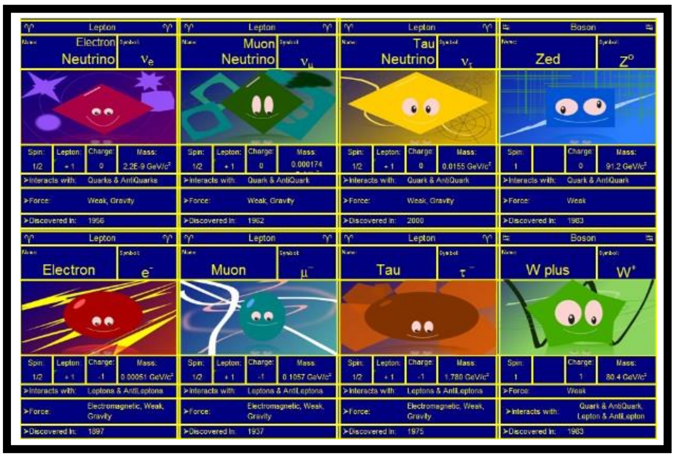
Students learn about the elementary particles and distinguish them between their families, in a playful yet structured way.

Goals

1. Learn about the interactions of subatomic particles.
2. Learn about the composition of matter.

3. Understand how and why the fundamental particles are used to build other particles following specific rules.
4. Understand whether and why certain interactions are allowed.
5. Understand the limitations of the Standard Model in explaining mass, gravity and other phenomena.

PHOTOS



2.7.2 Storytelling on a mission to Mars

Name of Best Practice	Storytelling on a Mission to Mars
Context	H2020 project

Target Group	Students 10 - 19 years old
Activity Setting	In school (preparation) : project or after- school hours
Geographical Coverage	International
Duration	N/A
Starting Date – Ending Date	2017 - ongoing
Number of teachers involved so far (Portugal only)	241
Number of students involved so far	1993
Organizing Institution	15 partners including NUCLIO and EA
Link	http://www.storiesoftomorrow.eu

General Description

Students create ebooks telling the story of a trip to Mars. The stories include episodes set on Earth, space and Mars. Students research themes connected to the subject of the story, and put to use their imagination to create a coherent narrative, not only through text, but also using images, sounds, animations and any other means they desire. Through storytelling, it is hoped that students can achieve deeper learning and do not lose their curiosity and interest in STEM subjects.

Overall Aim

Generate and maintain interest is STEM subjects through the use of a space setting for stories created by students with the aid of computers.

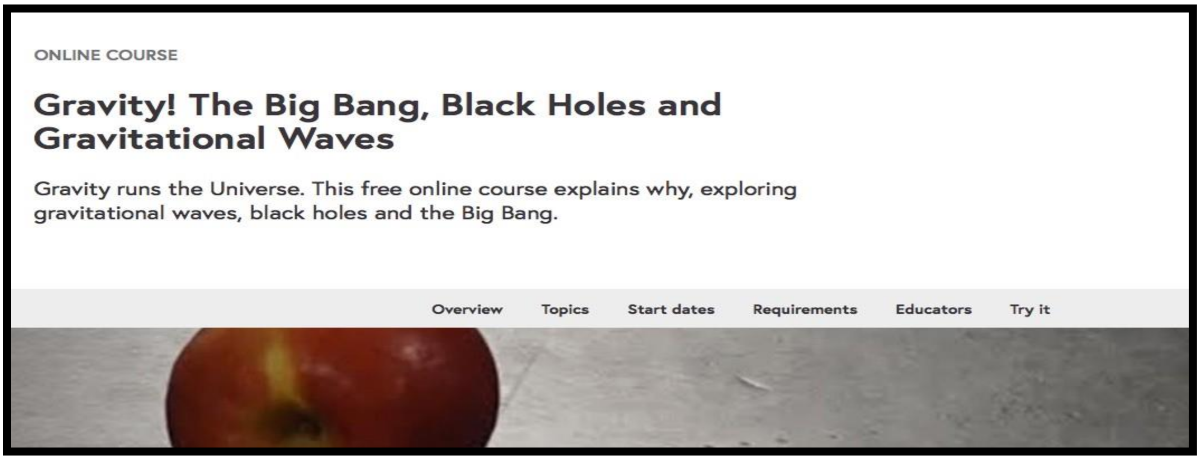
Goals

1. Motivate young students to develop their curiosity and interest in science
2. Develop cooperation skills in young students
3. Promote interdisciplinarity in teaching

4. Promote knowledge about space reality and contemporary research on life outside Earth

2.8 Online Courses

2.8.1 Massive Online Open Course (MOOC) on Gravity



Name of Best Practice	BeamLine 4 Schools Competition
Context	MOOC (massive open online course)
Target Group	General public
Activity Setting	Update of the existing MOOC
Geographical Coverage	International
Duration	7 weeks (course duration), but the course will remain open for participants
Starting Date – Ending Date	Fall 2019 (TBC) it can be repeated in 2020 or 2021
Number of teachers involved so far	2 leads educators + ~ 20 students and postdocs
Number of students involved so far	Several tens of thousands
Organizing Institution	PCCP

Link	https://www.futurelearn.com/courses/ gravity http://gravity.paris/en/index.php/category/blog/

General Description

This was a MOOC on gravity, black holes, gravitational waves and cosmology, with the participation of the Nobel Laureate George Smoot and the late Pierre Binetruy. It was implemented with the well-known FutureLearn platform and ran for 3 consecutive years with tremendous success (over 85000 subscribers, of which one third actively followed the course). Online discussions and hangouts were organized with over 1000 participants, managed by a pedagogical team consisting of professors, postdocs and PhD students. Direct connections were organized with the launch of the LISA Pathfinder and the announcement of the discovery of gravitational waves. For more details see http://gravity.paris/en/index.php/2015/12/24/what-are- mooc-projects-for/

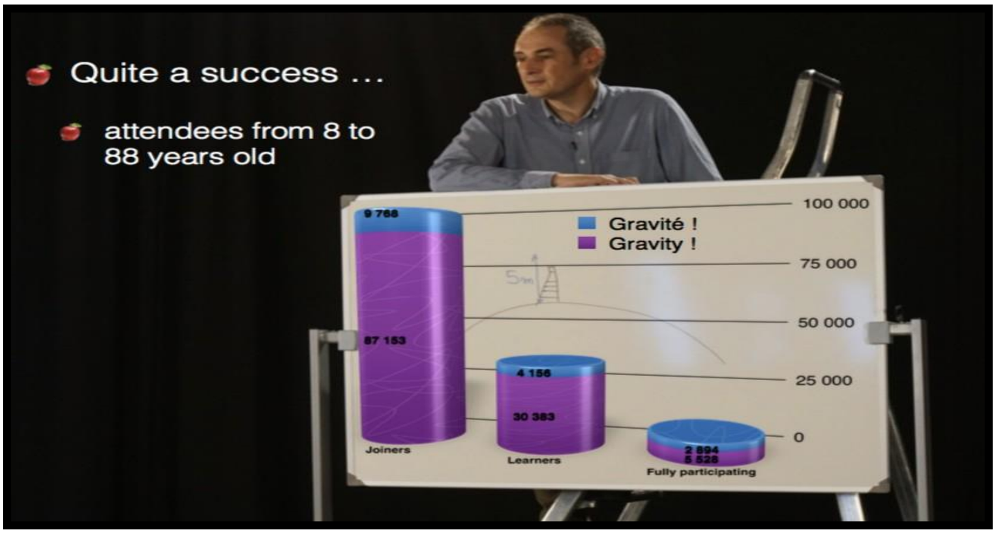
Overall Aim

Generate interest and understanding of what gravity and gravitational wave physics is all about.

Goals

1. Explore the modern concepts underlying the fundamental aspects of the physics of the Universe.
2. Design thought experiments that illustrate the basic properties of the gravitational force in familiar (on Earth) or unfamiliar (on the Moon, in space or close to black holes) settings.
3. Discuss with other learners the most subtle or most unusual properties of space and time in the context of gravity.
4. Experiment with gravity using simple experiments in order to better identify the basic concepts.
5. Investigate complementary aspects of gravity by researching science magazines or the web.

6. Debate about the present controversies in the physics of the Universe using the concepts learned in the course and scientific reasoning.



Section 3 Best Practices Characteristics

3.1 Demographics and Impact of the selected Best Outreach Practices

The selected FRONTIERS outreach practices have been identified following a first set of criteria as it has been described in section 1 of this document. This section presents an overall description of the best practices with respect to several indicators: the age group of the learners, the implementation duration and setting of these practices, the years of continuous implementations of the practices, the distribution of engaged students and teachers, the context and subject matter of the best practices, the use of online tools and existing research infrastructures as well as the availability of evaluation data for them. In this framework, the FRONTIERS consortium aims to identify characteristics of these best practices, which will prove important in their aggregation in the FRONTIERS demonstrators.

Subject Field Distribution of the FRONTIERS best practices.

The subject fields of the selected outreach practices represent the consortium's expertise in these fields. 25 practices have been examined regarding this indicator.

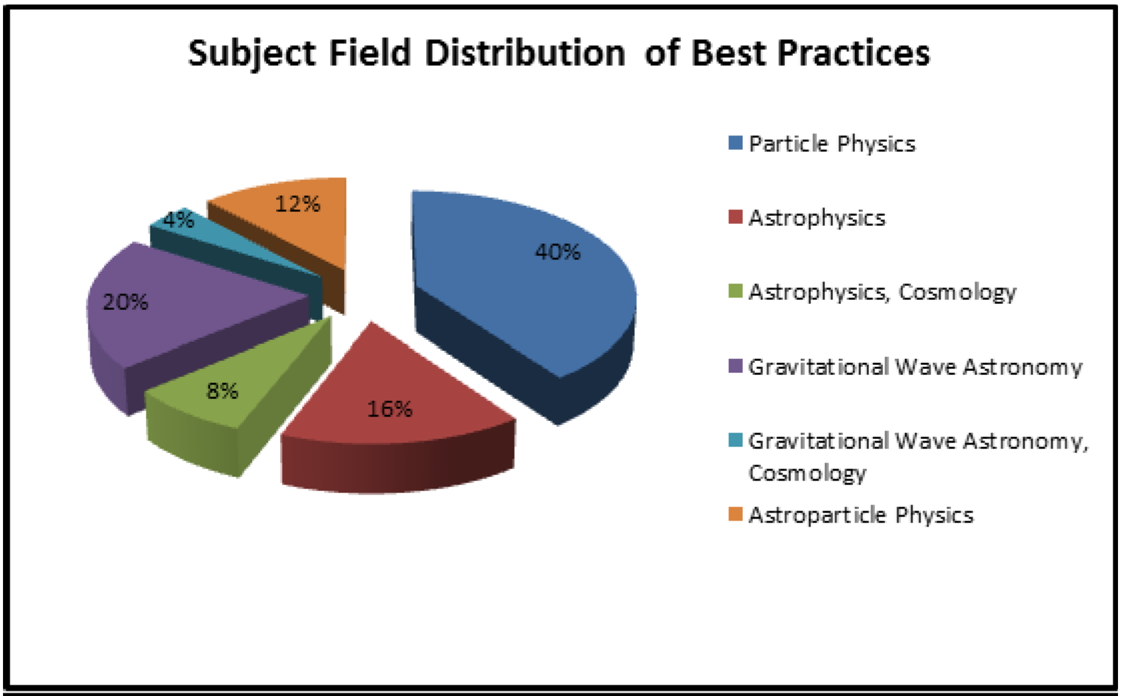


Figure 3.0 Subject Field Distribution of Best practices

Following the distribution presented in Fig 3.0, 40% of best practices come from the field of particle physics, while the field of astrophysics and cosmology represents 24% of these practices, Gravitational Wave Astronomy and Cosmology 24% of these practices and Astroparticle Physics 12% of these practices. These results are expected, as Particle Physics has a longer tradition of education and outreach using e-infrastructures with respect to the other disciplines, while other fields such as gravitational wave astronomy are quite new in the field of education and outreach.

Context and implementation setting of the FRONTIERS best outreach practices

The following figures present the context, implementation settings and implementation level of the FRONTIERS outreach practices.

Figure 3.1 Context of Best outreach practices

Observing Figure 3.1, we can see that there is a large diversity in the context of the best outreach practices, ranging from visits to research centers to research projects in school. This diversity signifies the different outreach channels that have been enabled in order to reach out to more students and provide an engaging introduction into Frontier Physics. FRONTIERS aims to capitalize from characteristics of these different approaches in order to integrate them in the FRONTIERS demonstrators, addressed by Intellectual Output 2. As the focus of the project is in teacher training and implementation with students, the challenge of aggregating characteristics of the selected best practices into engaging school activities can be identified.

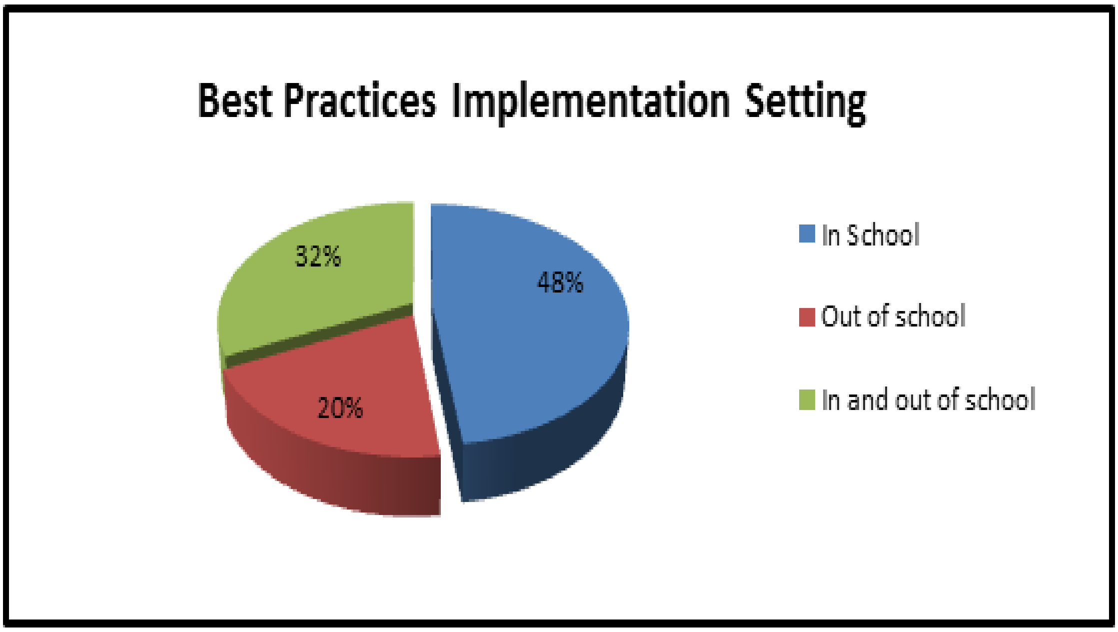


Figure 3.2 Best practices implementation setting

We can see that the majority of the selected outreach practices have been carried out in school settings, while others require work both in and out of school (such as the Cultural Collisions Best Practice), or totally out of school (such as the VIRGO Site Visits). In order to be able to design innovative activities that make the most out of the selected practices, modifications and alterations will need to be made in order to accommodate their implementation in a formal setting. One of the most important characteristics of an activity which introduces frontier Physics in secondary education is its potential to be used by any student without the need to visit a specific research infrastructure. To achieve this, activities that utilize real scientific data and online tools as well as provide access to existing research infrastructures in a remote fashion can be considered as optimal for further consideration.

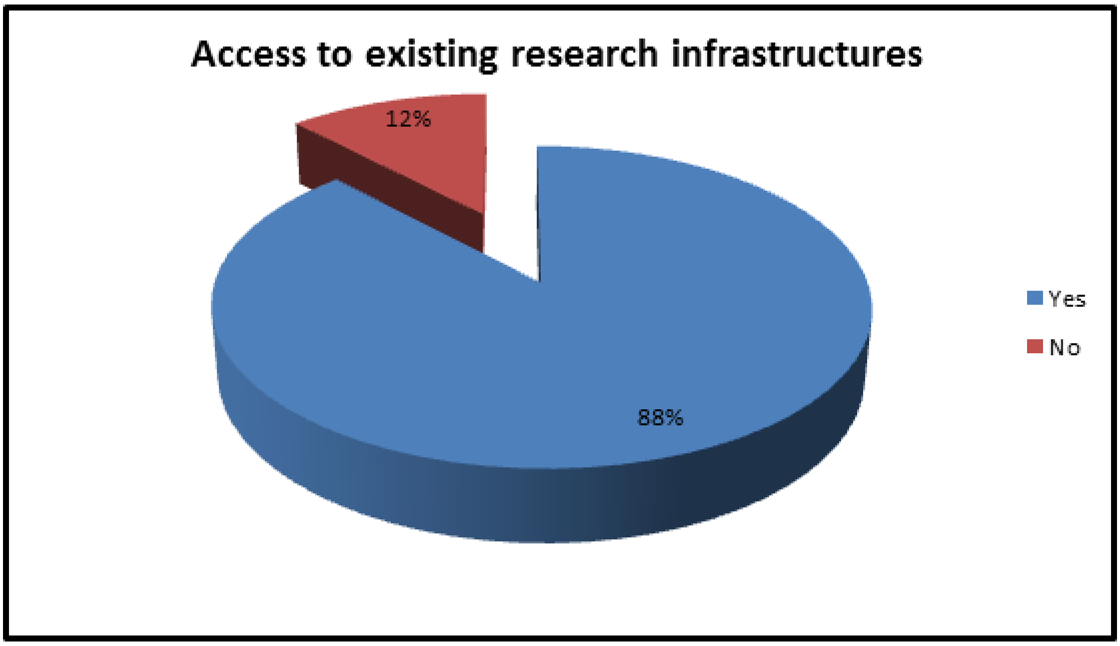


Figure.3.3: Best outreach practices distribution regarding the access to existing research infrastructures.

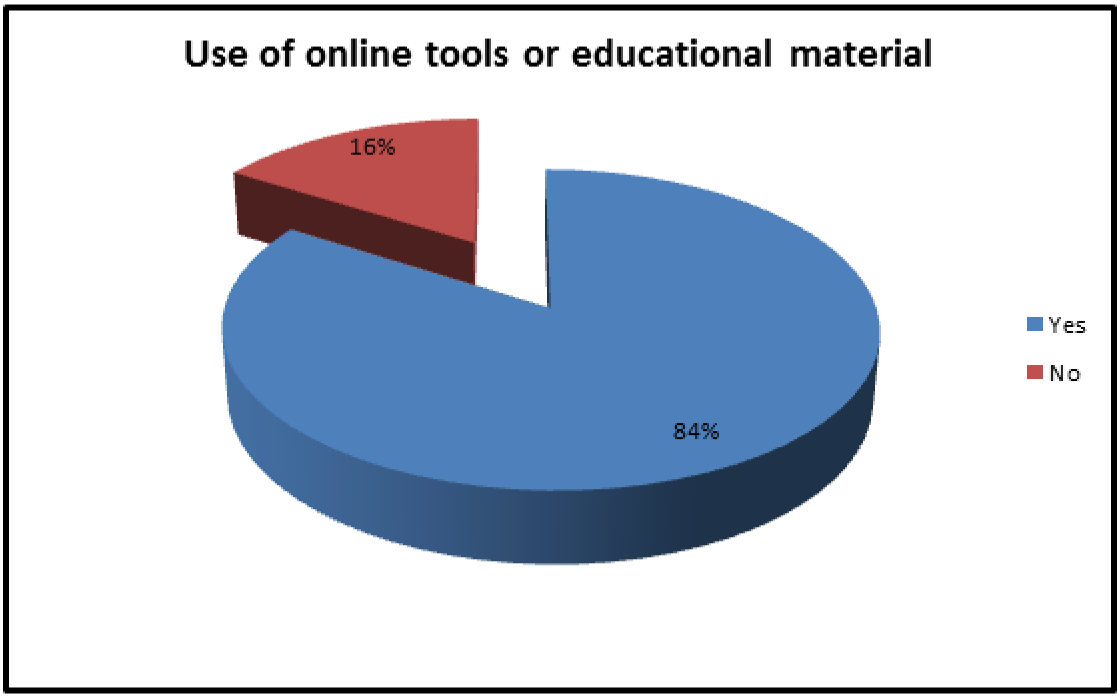


Figure. 3.4: Best outreach practices distribution regarding the use of online tools or educational material.

Figures 3.3 and 3.4 demonstrate that the majority of the selected best practices provide access to already existing research infrastructures and utilize online tools, data or educational material. Another aspect, which is considered very important in the design of implementations in a formal setting such as the school is the duration of the implementation of an outreach activity.

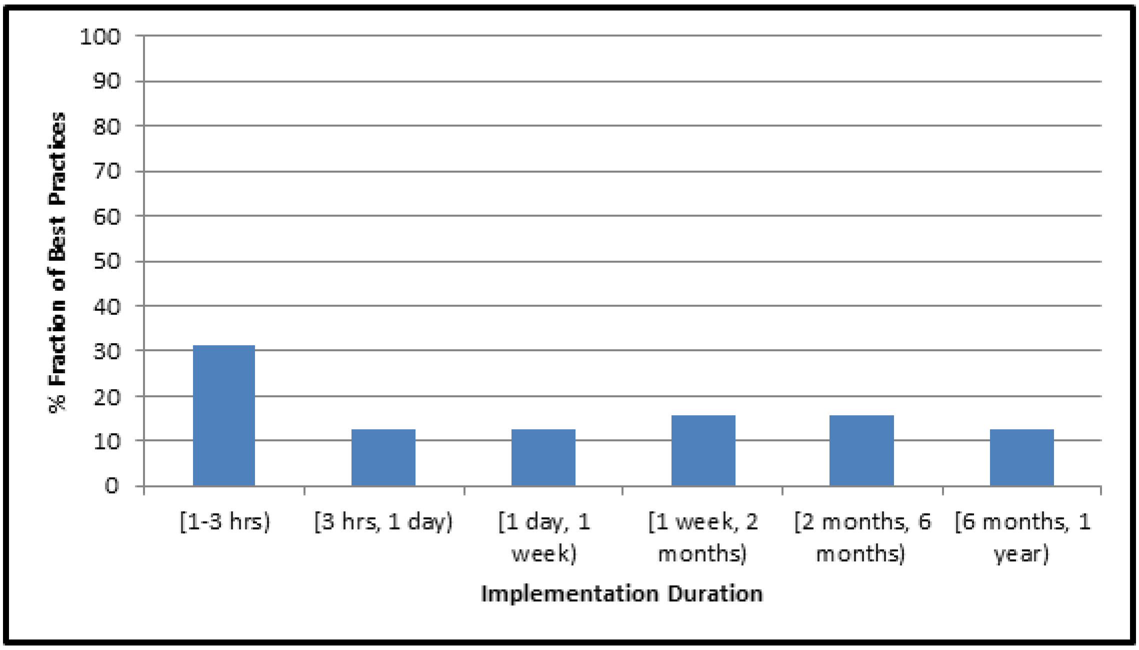


Figure. 3.5 The distribution of implementation durations for the different best practices

As illustrated in Figure 3.5, most of the selected outreach practices can be implemented in a 1-3 hour span. These activities coincide with in-classroom activities. Other activities that have been implemented have durations from 1 day to 1 full school year.

<u>Demographics and Impact of the selected Best Outreach Practices</u>

This section presents the demographics impact of the selected best outreach practices, as it can be quantified through a set of indicators: the implementation level of these practices, the numbers of students and teachers engaged and the profiles of the engaged students.

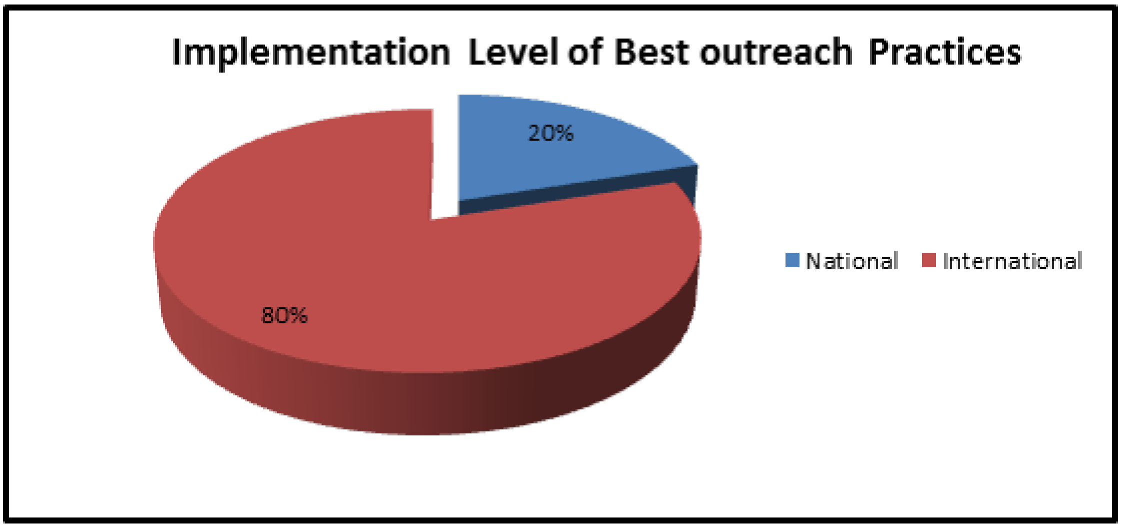


Figure. 3.6: Implementation Level of the FRONTIERS Best Outreach Practices.

As evident in Figure 3.6, most of the selected outreach practices have been implemented at international level, with more than 2 countries organizing them. This feature is indicative of the impact of the proposed practices and of the acceptance of such outreach initiatives in more than one country. Beyond the implementation level, a characteristic, which signifies the impact of these practices is the number of years of continuous implementation. Figure 3.7 displays the distribution of best practices with respect to years of continuous implementation.

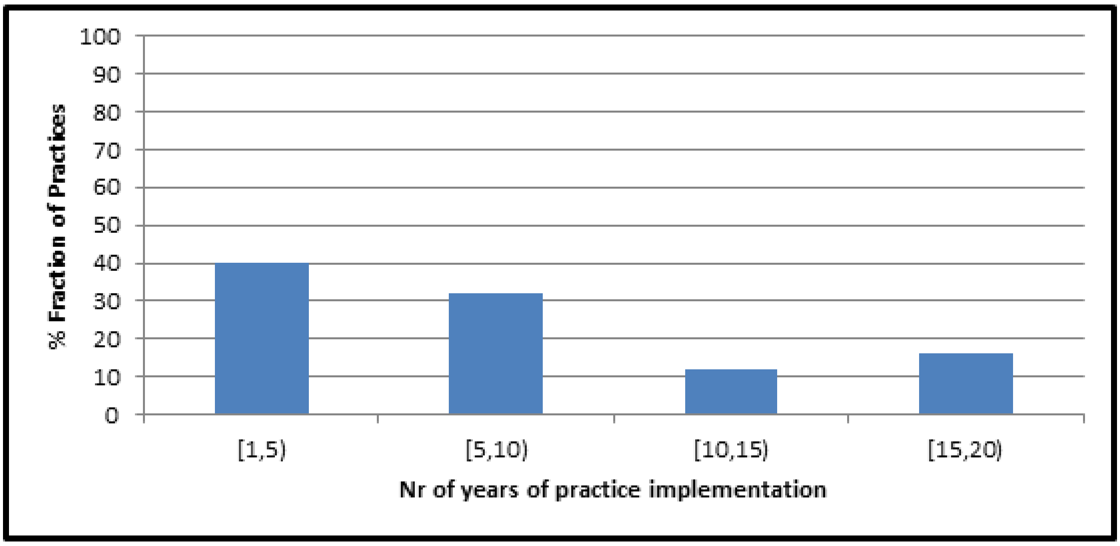


Figure. 3.7: Distribution of best practices with respect to their years of continuous implementation

We observe that the majority of best practices have been implemented for 1 to 5 years and 5 to 10 years while others such as the particle physics master classes have been implemented for more than 15 years. The end users/learners of these practices are students, while the facilitators in many cases are researchers from the groups organizing the practices or, in lower proportion, teachers who have been trained in the framework of these practices. Figure 3.8 presents the distribution of best practices with respect to the ages of the end users (learners). The terms used in the horizontal axis of this chart represent: UHS: Upper High School (15,18 year old students); JHS: Junior High School (12, 15 year old students); UPS: (10, 12 year old students). Many of the outreach practices can be implemented in one, two or all of these age groups, with the content discussed undergoing changes in order to be accessible to these students.

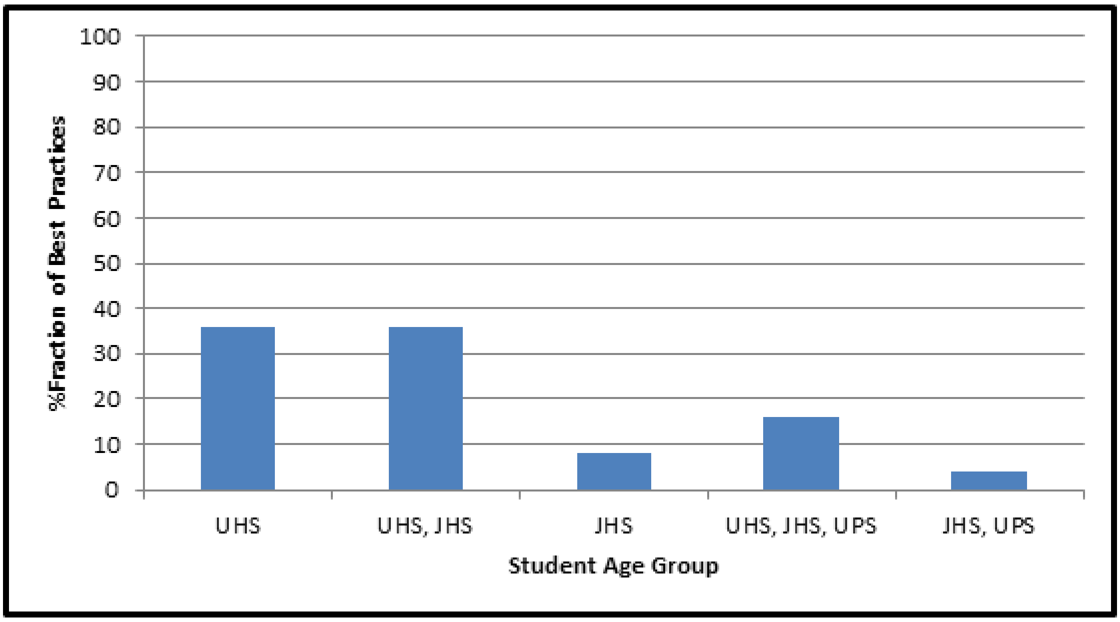


Figure. 3.8 Student distribution according to their age in the selected best practices.

As can be seen in Figure 3.8, the majority of best outreach practices address upper high school students as well as upper high school and junior high school students. This fact is expected due to the difficulty of the concepts addressed by the selected practices and is harmonized with our initial criterion of choosing practices that will not address primary school students alone.

Figures 3.9 and 3.10 present the distribution of best practices with respect to the number of engaged students as well as the number of engaged students with respect to the years of practice implementation distribution. 24 practices have been examined to this end, since one of them (Gravity Spy) didn't provide data specifically for students but in general for citizens without age tags.

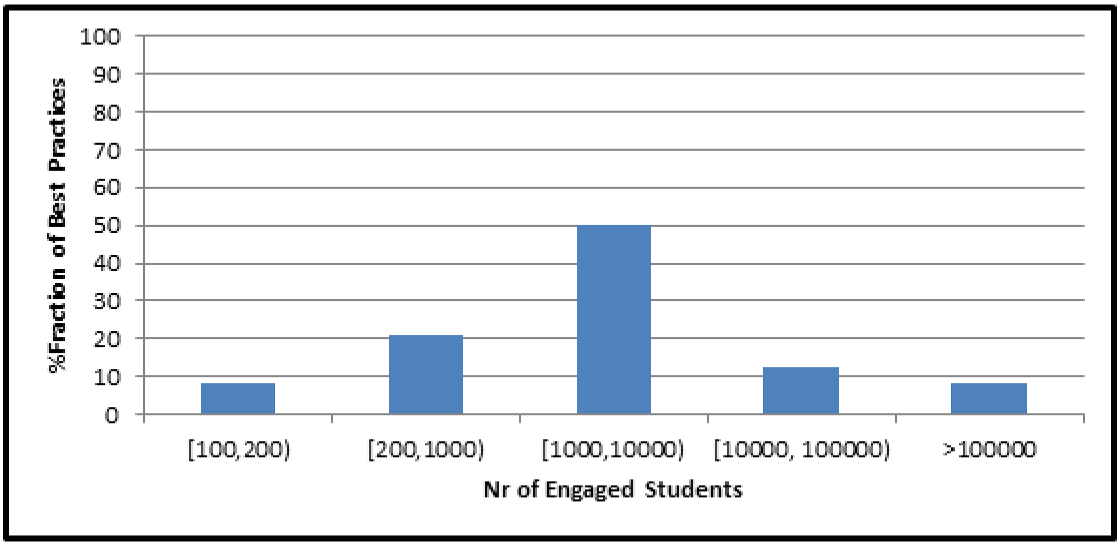


Figure. 3.9 The fraction of best practices with respect to the estimated number of engaged students for 24 out of 25 best practices.

We observe that the majority of the selected best practices have engaged a few thousand students throughout their duration.

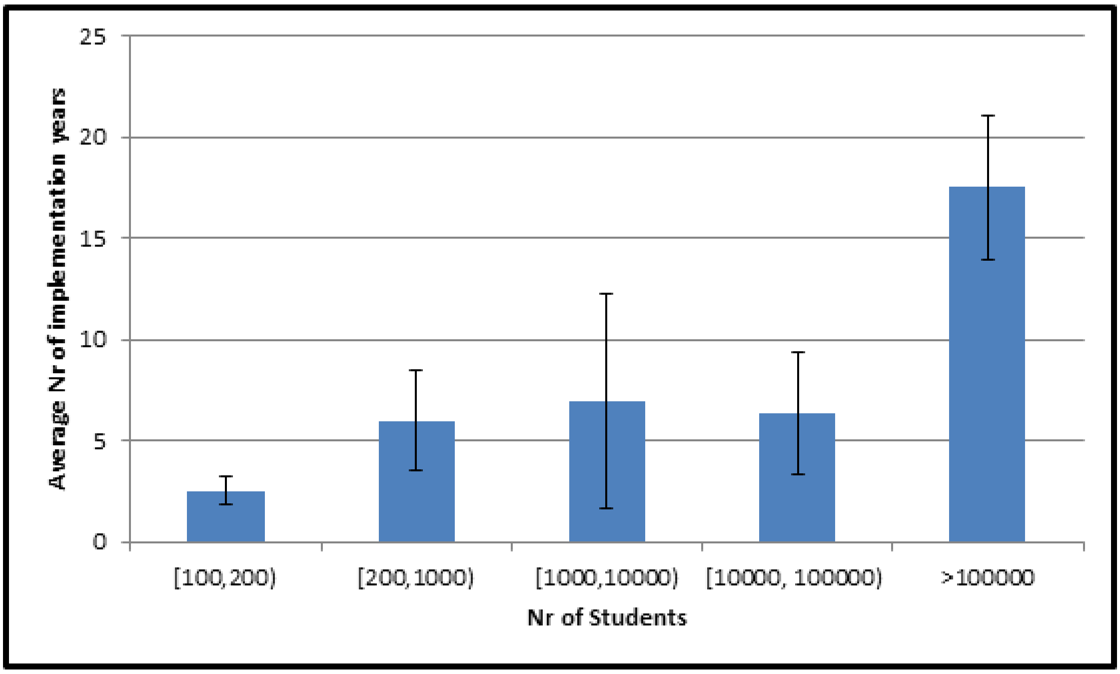


Figure. 3.10: Distribution of average number of implementation years with respect to the number of engaged students for 24 best practices. The error bars present the standard deviation of implementation years.

Figure 3.10 presents the average number of implementation years with respect to the number of engaged students in the selected best practices. We observe an increasing trend which is to be expected. However, we observe significant fluctuations in the standard deviation of the implementation years in the various engaged students which is to be expected due to the different contexts of the best practices.

The main role of the teacher in the majority of these practices is to support their implementation with the students. Figure 3.11 presents the distribution of best practices with respect to the number of engaged teachers. 20 out of the 25 best practices were examined due to the availability of data with respect to this indicator.

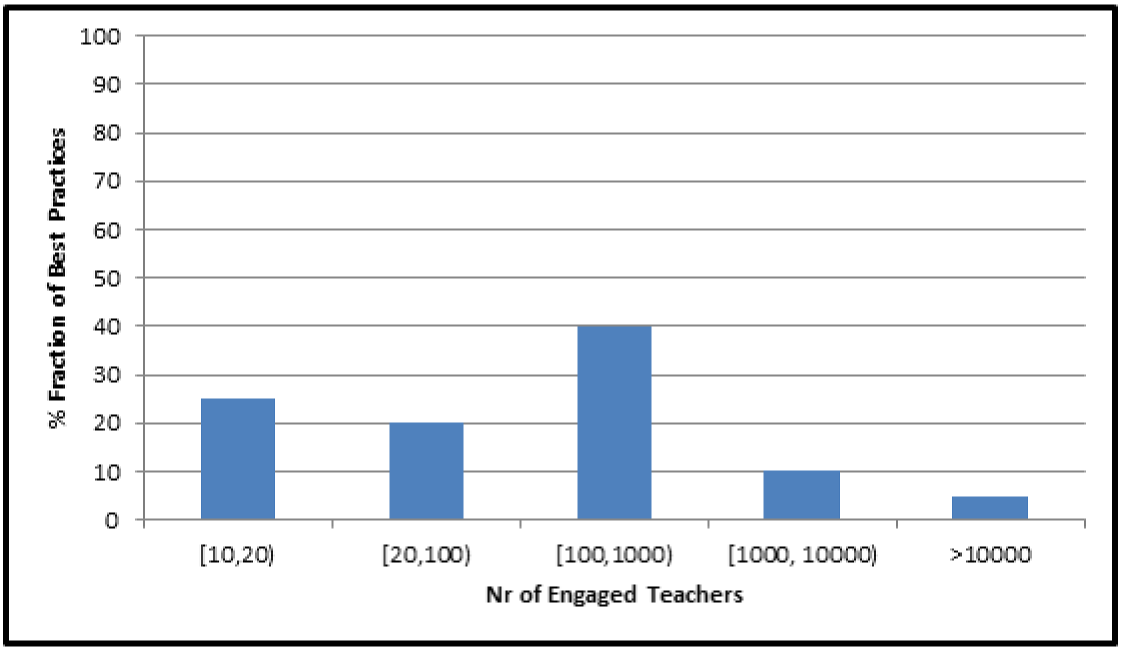


Figure. 3.11 Distribution of best practices with respect to the number of engaged teachers

We observe that teachers are scaled down by a factor of 10 with respect to the engaged students. However, the shape of the distributions of students and teachers differ. The median of the teacher distribution is shifted towards the left side of the distribution while the median of the student distribution is in the middle.

This effect corresponds to the field observed fact that the facilitators of the best practices in many cases are researchers and outreach specialists who have been involved in the development and the implementation of an outreach activity, while teachers are more limited in supporting the implementation of these facilitators. In some cases, teachers do not receive training in order to implement the activities themselves in the classroom, while in other cases, despite the training received teachers do not feel confident to implement the activities on their own without the support of a specialist in the respective practice.

FRONTIERS aims to reverse this trend by bringing teachers to the forefront. To achieve that, specific teacher training will be designed and the teachers will be empowered to implement the FRONTIERS demonstrators on their own in the classroom, while they will be supported by the FRONTIERS specialists through the project's community support environment.

<u>Publications and availability of evaluation data</u>

A final examination of the selected best practices has been made with respect to the availability of evaluation data regarding students' learning as well as the existence of publications in the form of peer reviewed papers or conference proceedings.

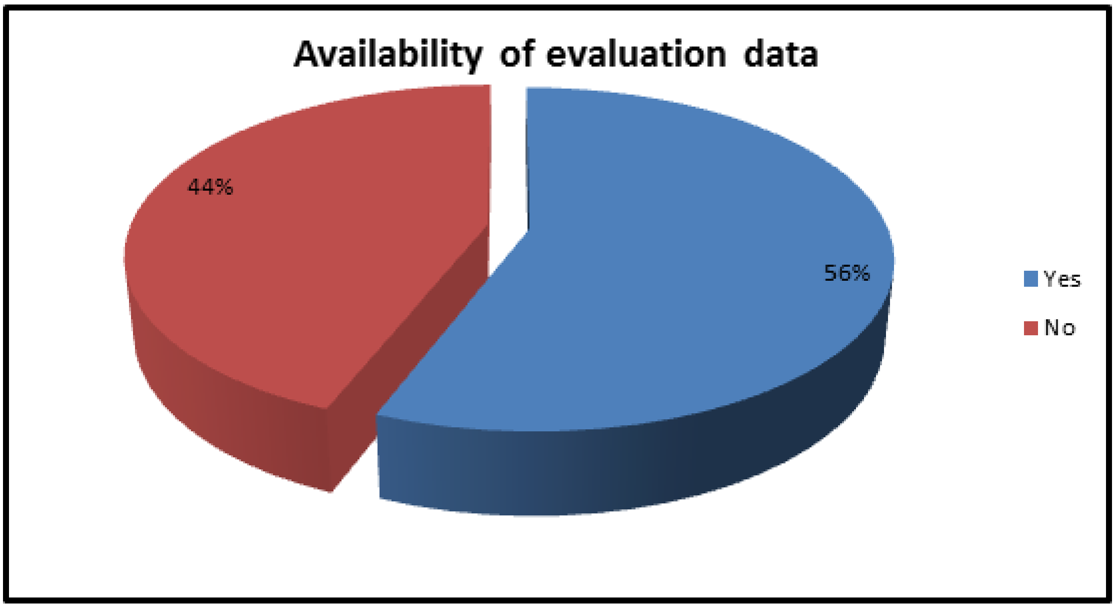


Figure. 3.12: Availability of evaluation data for the selected best practices

Figure 3.12 presents the distribution in the availability of evaluation data regarding the learning outcomes of the selected best practices. We observe that 44% of the selected practices do not present evaluation data.

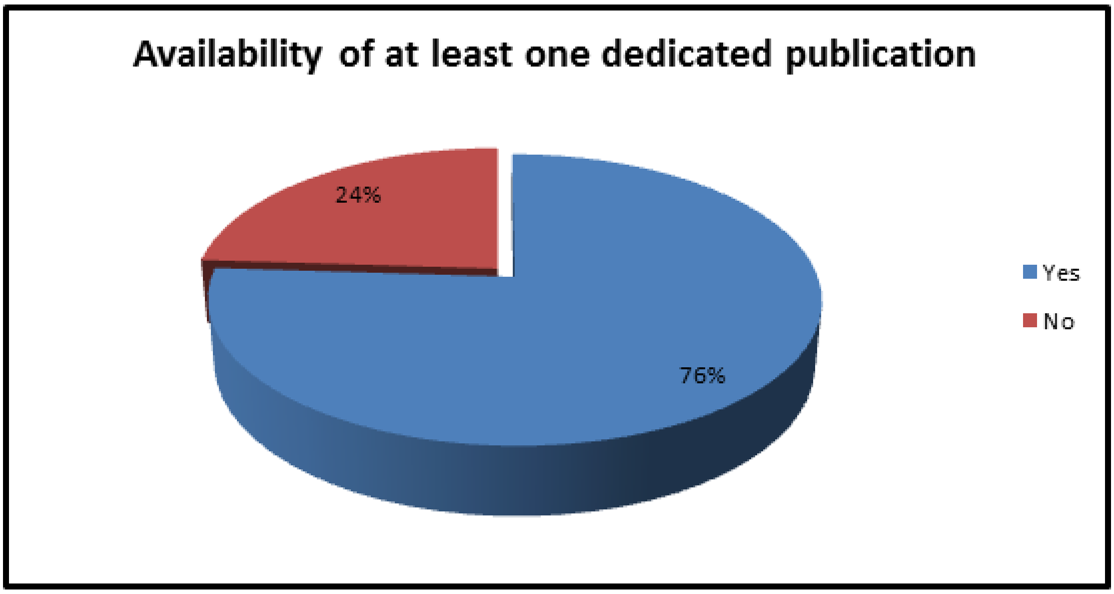


Figure. 3.13: Availability of dedicated publications for the selected best practices

Figure 2.13 presents the availability of dedicated publications for the selected best practices. We observe that the majority of the selected best practices have at least one dedicated publication either in a peer-reviewed journal or in a conference.

Conclusions

Following the considerations presented in this section, the following key messages can be identified:

- The Selected Best Practices display subject field diversity which represents the expertise of the members of the consortium. FRONTIERS aim to support, through its demonstrators, education and outreach activities both in established fields such as Particle Physics and Astronomy and in emerging fields such as Gravitational Wave Astronomy and Astroparticle Physics.

- The selected best practices have been implemented in different contexts: from activities with data to touring/visiting exhibitions. In the framework of the design of the FRONTIERS demonstrators, we intend to learn from these practices, aggregate characteristics which can be implemented in formal settings and also provide additional characteristics which are context specific.

- The majority of the selected best practices are being implemented internationally in schools and utilizes online data and existing research infrastructures. This feature is very important for the integration of these best practices in the demonstrators.

- The majority of the selected best practices are short-term activities, which have been implemented within a few hours time frame.

- The majority of the selected best practices have been active for the past 1 to 5 years whilst some practices have been actively used for more than 15 years.

- The numbers of students engaged in these practices span from hundreds to tens of thousands. This number depends both in the time that the selected activities have been active as well as the nature of the activities themselves and the duration of their implementation.

- The number of teachers engaged in each outreach practice is an order of magnitude smaller than the number of students. However, the teacher distribution is shifted towards low numbers. This fact can be combined with the field observation that the main facilitators in the majority of these best practices are outreach experts and not teachers themselves. In order to rectify this, in the framework of FRONTIERS, specific teacher training will be designed and the teachers will be empowered to implement the demonstrators on their own in the classroom, while the FRONTIERS specialists through the project's community support environment support them.

- A high fraction, albeit the minority of the selected best practices have no evaluation data available regarding the learning outcomes for students. To investigate further the added value of bringing frontier Physics in the classroom, FRONTIERS will propose an evaluation framework which will be used in the implementation of the FRONTIERS best-practices inspired demonstrators.

- It is clear that all outreach practices span the different levels of the cognitive domain. 50% of the practices are in the highest level of Creating, 20% in

Applying but most of the outreach practices are in the lower levels of Remembering and Understanding. This needs to be addressed when preparing the demonstrators.

- Additionally, it is positive to note that a high number of the practices (over 75%) include collaboration and communications.

- There were fewer opportunities presented within the outreach practices for developing a new physical behaviour but perhaps this can be explored further when developing the demonstrators.

- ICT literacy is strongly represented in over 80% of the outreach practices. This shows that a high number of the outreach practices require students to make use of technology as part of the practice.

- Initiative, self-direction and social and cross-cultural interaction are included in over 82% of the best practices. This is important in the selection of the outreach practices.

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