CERNgineers: Creative engineering in the search of Universe's structure

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1 Introduction / Demonstrator Identity

1.1 Subject Domain

Particle physics, physics, engineering, STEM.

1.2 Type of Activity

School – based activities. CERNgineering activities can also be introduced during science fair festivals

1.3 Duration

3 x 90’

1.4 Setting (formal / informal learning)

The setting is mainly formal (i.e. school) but can also be informal (e.g. science cafè, science fair) and engages multiple actors including students, teachers, scientists, parents and general public

1.5 Effective Learning Environment

- **Communities of practice (web-based/physical):** children work together in an immersive environment of engineering activities. They contact and talk with engineers from various work settings (e.g. tunnel building sector, detector engineering e.g. geospacial enabling technologies, home security systems, road traffic reporting, etc.)
- **Arts-based:** the design and implementation of engineering plans involves children’s artistic self-expression as well.
- **Dialogic space / argumentation:** through questioning and dialog children are allowed to express their views regarding scientific research and explain their choices regarding their own engineering artifacts.
- **Visits to research centres (virtual/physical):** children make use of CERN virtual tours to explore the LHC, the CERN experiment sites and the CERN premises.
- **Communication of scientific ideas to audience:** children present their artifacts to the public and explain the underlying technical details and how their artifacts relate to the particle physics experiments.

2 Rational of the Activity / Educational Approach

2.1 *Challenge*

(Description of the problem)

At CERN, the European Organization for Nuclear Research, physicists and engineers use the world's largest and most complex scientific instruments to study the basic constituents of matter – the fundamental particles (https://home.cern/about). Education needs to follow up so that pupils get close to the forefront of engineering developments and scientific research.

Even though educating children of younger ages in particle physics is very important for advancement of science, in the long run, and, at the same time, triggers children's interest (Pavlis, 2016), only 3 educational articles have been published over the last 20 years, which focus on particle physics education in primary education context (ERIC database - https://eric.ed.gov/?) .

This demonstrator addresses the above need through employing engineering and scientific research activities as a means to simulate and immerse pupils in the culture of the CERN experimental processes. Children develop an understanding of particle physics through facing engineering challenges and visualize, design and construct their own CERN tunnels, accelerators and detectors using simple, everyday objects.

2.2 *Added Value*

(Elaboration of the applied creative approaches and their purpose)

CERN mission's is to advance scientific research but this is done in an interdisciplinary way with thousand professionals representing multiple disciplines collaborate towards common goals. This means that the process of learning about particle physics has to embrace a corresponding interdisciplinary approach. That is why this demonstrator draws upon the recently popularised STEM education approach (Science, Technology, Engineering and Mathematics), which offers children the opportunity to realize that the advancement of knowledge is depended on tackling challenges, synthesising information and collaborating. This is the interdisciplinary culture we have to educate our children in.

STEM education not only prepares children for the emerging scientific world and the future study and work and choices of career. It helps them shape their intellectual development and their capacity to make informed decisions about political and civic issues and about their own lives (Beatty, 2011). Hands on approach to learning is child-friendly and coincides with the holistic way children perceive the world. Apart from that the problem based learning that is inherent in the

STEM education has all the benefits of PBL approaches including high levels of pupil engagement with tasks and creativity.

"During STEM programming, students are creating their own research questions and following a process that helps them learn to investigate multiple perspectives and connect ideas to solve a problem. Whether it's the Engineering Design Process, the Design-Thinking Process, or the Scientific Method, your kids are going to be collaborating with others; asking important questions; taking leadership in their roles; and testing many ideas to reach a solution." (http://www.stemvillage.com/).

3 Learning Objectives

3.1 Domain specific objectives

The main objectives of the teaching intervention are:

- To realize that matter is made up of elementary particles which are structured into larger particles, for example protons, neutrons and eventually atoms
- To explain the methods that physicists at CERN follow to understand the fundamental structure of the universe.
- To explore CERN sites and learn about the role of CERN in advancing research in particle physics
- To explain in a simple way how the Large Hadron Collider (LHC) works.
- To understand that particle physicists collide particles to reveal their inner structure
- To explain in a simple way how particle detectors work and what is their role in the CERN experiments

3.2 General skills objectives

The main objectives are:

- To develop critical thinking and creative thinking skills while facing creative challenges.
- To develop engineering skills while trying out practical solutions to challenges.
- To cooperate effectively with other students
- To develop presentation skills of communicating physics and engineering ideas
- To appreciate the cooperation of different professionals in designing, constructing and operating the world's largest and most complex scientific instruments

4 Demonstrator characteristics and Needs of Students

4.1 Aim of the demonstrator

The demonstrator aims at describing a series of lessons and activities designed to engage students in hands-on engineering experiences, in order to improve their understanding of particle physics. Inspired by CERN facilities and experiments, pupils face engineering challenges and visualize, design, and construct their own CERN tunnels, accelerators and detectors using everyday and simple objects.

4.2 Student needs addressed

Affective

- Experience feelings of joy and satisfaction
- Experience pleasure associated with physical movement and manipulation of materials

Cognitive

- Satisfy curiosity about the structure of the cosmos and the way scientists try to decode universe's secrets
- Gaining basic knowledge and making sense of the way LHC and detectors are functioning
- Game playing and interaction with others (adults, specialists, other students)
- Engaging in fun group activities that has a clear educational purpose
- Freedom of expression to choose their preferred way of designing a particle model
- Develop a sense of self-confidence and pride in mastering particle physics concepts

Social

- Giving to others and obtaining approval, support, assistance, advice or validation from others.
- Experience a sense of freedom to act or make choices.

Task oriented

- Engaging in activities involving creativity
- Meeting high standards of achievement or improvement

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5 Learning Activities & Effective Learning Environments

Science topic: Particle physics, physics, engineering, STEM. (Relevance to national curriculum) Grades 5 and 6 _ Science Education Class information Year Group: 5-6 Age range: 9-12 Sex: both Pupil Ability: e.g. (The scenario allows space for pupils of various abilities to participate) all inclusive NOTE: Children of younger ages can be involved in the activities in a playful way and with an emphasis on artistic creations.	Materials and Resources *What do you need? (eg.*printed questionnaires, teleconference, etc.) • Power point presentation on (a) the world of particles, (b) the CERN site and facilites and (c) how LCH and a detector works. • Materials for engineering activities • Teacher guidelines *Where will the learning take place?* In school *On site or off site?* On site *In several spaces? (e.g. science laboratory, drama space etc), or one?* In a room that can facilitate lecture and group work *Health and Safety implications?* none *Technology?* Projector for power point presentation *Teacher support?* Yes. To encourage and help as necessary

Prior pupil knowledge

The standard model – the world of particles

Individual session project objectives *(What do you want pupils to know and understand by the end of the lesson?)*

During this scenario, students will

Session 1 (power point presentation): Building underground (learn about CERN site and excavations)

Engineer challenge: Build the LHC tunnel!

Session 2 (power point presentation _ videos _interactive games): The LHC (learn the physics and engineering of the LHC)
Engineer challenge: Construct an accelerator! (Use of everyday objects to construct a pipeline for accelerating marbles)

Session3 (power point presentation _ videos _interactive games): The detectors (learn the physics and engineering of the detectors)
Engineer challenge: Construct a detector! (Construct an everyday "particle" detector)

Assessment	**Differentiation**	**Key Concepts and Terminology**
Accomplishment of engineering challenges - Questioning and dialog through all sessions	*How can the activities be adapted to the needs of individual pupils?*	**Science terminology:**

	Students have the freedom of choice regarding their choices of materials and method of work during engineer challenges.	**Particle physics, particles, particle accelerator, excavations, detectors, CERN** **Arts terminology: video, painting, installation art, literature**
SESSION I		
Session Objectives: Pupils will take an overview of the CERN site and develop an understanding of the human endeavor in constructing those facilities that enable the research on the fundamental structure of the universe.		

Learning activities in terms of CREATIONS Approach				
IBSE Activity	**Interaction with CREATIONs Features**	**Student**	**Teacher**	**Potential arts activity**
Phase 1: **QUESTION:** students investigate a scientifically oriented question	Students pose, select, or are given a scientifically oriented question to investigate. *Balance and navigation* through *dialogue* aids teachers and students in creatively navigating educational tensions, including between open and structured approaches to IBSE. Questions may arise through *dialogue* between students' scientific knowledge and the scientific knowledge of professional scientists and science educators, or through *dialogue* with different ways of knowledge inspired by *interdisciplinarity* and personal, embodied learning. *Ethics and trusteeship* is an important consideration in experimental design and collaborative work, as well as in the initial choice of question.	Engage with teacher's questions. Watch power point presentation and demos. Pupils gain knowledge concerning the main experiments that take place in CERN. They observe that experiment sites are built over the LHC path	Teacher will use challenging questions pictures and demos involving the students to attract the students' interest in the CERN cite and facilities.	**None at this stage**

Phase 2: **EVIDENCE:** students give priority to evidence	Students determine or are guided to evidence/data, which may come from *individual, collaborative and communal activity* such as practical work, or from sources such as data from professional scientific activity or from other contexts. *Risk, immersion and play* is crucial in *empowering* pupils to generate, question and discuss evidence.	Pupils engage in engineering activity of tunnel building	Teacher question students to ensure links between observations and conclusions are understood.	**Pupils decorate their models**
Phase 3: **ANALYSE:** students analyse evidence	Students analyse evidence, using *dialogue* with each other and the teacher to support their developing understanding.	Pupils discuss about the challenge: What proved effective in completing the challenge effectively? What didn't work?	Teacher question students to ensure links between observations and conclusions are understood.	N/A
Phase 4: **EXPLAIN:** students formulate an explanation based on evidence	Students use evidence they have generated and analysed to consider *possibilities* for explanations that are original to them. They use argumentation and *dialogue* to decide on the relative merits of the explanations they formulate, *playing* with ideas.	Pupils develop a comprehensive idea of the difficulties and challenges of the underground constructions	Teacher facilitates and supports as required.	N/A
Phase 5: **CONNECT:** students connect explanations to scientific knowledge	Students connect their explanations with scientific knowledge, using *different ways of thinking and knowing* ('knowing that', 'knowing how', and 'knowing this') to relate their ideas to both disciplinary knowledge and to *interdisciplinary* knowledge to understand the origin of their ideas and reflect on the strength of	Pupils discuss with professionals about the challenges they face during their work.	Teacher invites professionals of the filed and facilitates and supports as required	**N/A**

	their evidence and explanations in relation to the original question.			
Phase 6: **COMMUNICATE:** students communicate and justify explanation	Communication of *possibilities*, ideas and justifications through *dialogue* with other students, with science educators, and with professional scientists offer students the chance to test their new thinking and experience and be *immersed* in a key part of the scientific process. Such communication is crucial to an *ethical* approach to working scientifically.	Students present their work, after dialog and collaboration within the group, to an audience of students and teachers. They can design and develop a CERN model.	Teacher facilitates and supports as required	**Presentation and explanation of choices in constructions**
Phase 7: **REFLECT:** students reflect on the inquiry process and their learning	*Individual, collaborative and community-based* reflective *activity for change* both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education.	Students are questioned about the new acquired knowledge at the end of the session as well as to evaluate the process and learning experience.	Teacher initiates the evaluation through dialog and collects and acts on feedback.	**N/A**

SESSION II
Session Objectives: Pupils will take an overview of the LHC and develop an understanding of it's characteristics and function
Learning activities in terms of CREATIONS Approach

IBSE Activity	Interaction with CREATIONs Features	Student	Teacher	Potential arts activity
Phase 1: **QUESTION:** students investigate a scientifically oriented question	Students pose, select, or are given a scientifically oriented question to investigate. *Balance and navigation* through *dialogue* aids teachers and students in creatively navigating educational tensions, including between open and structured approaches to IBSE. Questions may arise through *dialogue* between students' scientific knowledge and the scientific knowledge of professional scientists and science educators, or through *dialogue* with different ways of knowledge inspired by *interdisciplinarity* and personal, embodied learning. *Ethics and trusteeship* is an important consideration in experimental design and collaborative work, as well as in the initial choice of question.	Engage with teacher's questions. Watch power point presentation and demos. Pupils gain knowledge concerning the LHC	Teacher will use challenging questions pictures and demos involving the students to attract the students' interest in the LHC	**None at this stage**
Phase 2: **EVIDENCE:** students give priority to evidence	Students determine or are guided to evidence/data, which may come from *individual, collaborative and communal activity* such as practical work, or from sources such as data from professional scientific activity or from other contexts. *Risk, immersion and play* is crucial in *empowering* pupils to generate, question and discuss evidence.	Pupils engage in engineering activity of constructing an "LHC pipeline"	Teacher question students to ensure links between observations and conclusions are understood.	**Pupils construct and decorate their LHC models**
Phase 3: **ANALYSE:** students analyse evidence	Students analyse evidence, using *dialogue* with each other and the teacher to support their developing understanding.	Pupils discuss about the challenge: What proved effective in completing the challenge	Teacher question students to ensure links between observations and	N/A

		effectively? What didn't work?	conclusions are understood.	
Phase 4: **EXPLAIN:** students formulate an explanation based on evidence	Students use evidence they have generated and analysed to consider *possibilities* for explanations that are original to them. They use argumentation and *dialogue* to decide on the relative merits of the explanations they formulate, *playing* with ideas.	Pupils develop a comprehensive idea of the difficulties and challenges of the underground constructions	Teacher facilitates and supports as required.	N/A
Phase 5: **CONNECT:** students connect explanations to scientific knowledge	Students connect their explanations with scientific knowledge, using *different ways of thinking and knowing* ('knowing that', 'knowing how', and 'knowing this') to relate their ideas to both disciplinary knowledge and to *interdisciplinary* knowledge to understand the origin of their ideas and reflect on the strength of their evidence and explanations in relation to the original question.	Pupils discuss with professionals about the challenges they face during their work.	Teacher invites professionals of the field and facilitates and supports as required	**N/A**

Phase 6: **COMMUNICATE:** students communicate and justify explanation	Communication of *possibilities*, ideas and justifications through *dialogue* with other students, with science educators, and with professional scientists offer students the chance to test their new thinking and experience and be *immersed* in a key part of the scientific process. Such communication is crucial to an *ethical* approach to working scientifically.	Students present their work, after dialog and collaboration within the group, to an audience of students and teachers.	Teacher facilitates and supports as required	**Presentation and explanation of choices in constructions**
Phase 7: **REFLECT:** students reflect on the inquiry process and their learning	*Individual, collaborative and community-based* reflective *activity for change* both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education.	Students are questioned about the new acquired knowledge at the end of the session as well as to evaluate the process and learning experience.	Teacher initiates the evaluation through dialog and collects and acts on feedback.	**N/A**

SESSION III
Session Objectives: Pupils will take an overview of the particle detectors and develop an understanding of their characteristics and function
Learning activities in terms of CREATIONS Approach

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IBSE Activity	Interaction with CREATIONs Features	Student	Teacher	Potential arts activity
Phase 1: **QUESTION:** students investigate a scientifically oriented question	Students pose, select, or are given a scientifically oriented question to investigate. *Balance and navigation* through *dialogue* aids teachers and students in creatively navigating educational tensions, including between open and structured approaches to IBSE. Questions may arise through *dialogue* between students' scientific knowledge and the scientific knowledge of professional scientists and science educators, or through *dialogue* with different ways of knowledge inspired by *interdisciplinarity* and personal, embodied learning. *Ethics and trusteeship* is an important consideration in experimental design and collaborative work, as well as in the initial choice of question.	Engage with teacher's questions. Watch power point presentation and demos. Pupils gain knowledge concerning the particle detectors	Teacher will use challenging questions pictures and demos involving the students to attract the students' interest in the particle detectors	**None at this stage**
Phase 2: **EVIDENCE:** students give priority to evidence	Students determine or are guided to evidence/data, which may come from *individual, collaborative and communal activity* such as practical work, or from sources such as data from professional scientific activity or from other contexts. *Risk, immersion and play* is crucial in *empowering* pupils to generate, question and discuss evidence.	Pupils engage in engineering activity of constructing a "particle detector"	Teacher question students to ensure links between observations and conclusions are understood.	**Pupils construct and decorate their "detectors"**
Phase 3: **ANALYSE:** students analyse evidence	Students analyse evidence, using *dialogue* with each other and the teacher to support their developing understanding.	Pupils discuss about the challenge: What proved effective in completing the challenge	Teacher question students to ensure links between observations and	N/A

		effectively? What didn't work?	conclusions are understood.	
Phase 4: **EXPLAIN:** students formulate an explanation based on evidence	Students use evidence they have generated and analysed to consider *possibilities* for explanations that are original to them. They use argumentation and *dialogue* to decide on the relative merits of the explanations they formulate, *playing* with ideas.	Pupils develop a comprehensive idea of the difficulties and challenges of constructing a particle detector	Teacher facilitates and supports as required.	N/A
Phase 5: **CONNECT:** students connect explanations to scientific knowledge	Students connect their explanations with scientific knowledge, using *different ways of thinking and knowing* ('knowing that', 'knowing how', and 'knowing this') to relate their ideas to both disciplinary knowledge and to *interdisciplinary* knowledge to understand the origin of their ideas and reflect on the strength of their evidence and explanations in relation to the original question.	Pupils discuss with professionals about the challenges they face during their work.	Teacher invites professionals of the field and facilitates and supports as required	**N/A**

Phase 6: **COMMUNICATE:** students communicate and justify explanation	Communication of *possibilities*, ideas and justifications through *dialogue* with other students, with science educators, and with professional scientists offer students the chance to test their new thinking and experience and be *immersed* in a key part of the scientific process. Such communication is crucial to an *ethical* approach to working scientifically.	Students present their work, after dialog and collaboration within the group, to an audience of students and teachers.	Teacher facilitates and supports as required	**Presentation and explanation of choices in constructions**
Phase 7: **REFLECT:** students reflect on the inquiry process and their learning	*Individual, collaborative and community-based* reflective *activity for change* both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education.	Students are questioned about the new acquired knowledge at the end of the session as well as to evaluate the process and learning experience.	Teacher initiates the evaluation through dialog and collects and acts on feedback.	**N/A**

6 Additional Information

The CERNgineers educational initiative was introduced in the 1st Primary School of Rafina during school-year 2016-2017.

Picture 1. First graders working with the "clouds" of the CERN's CLOUD Experiment

First graders (6 years old children) followed mostly sensory, artful and simple educational activities which, at the same time, reflected main physics concepts and studies conducted at CERN.

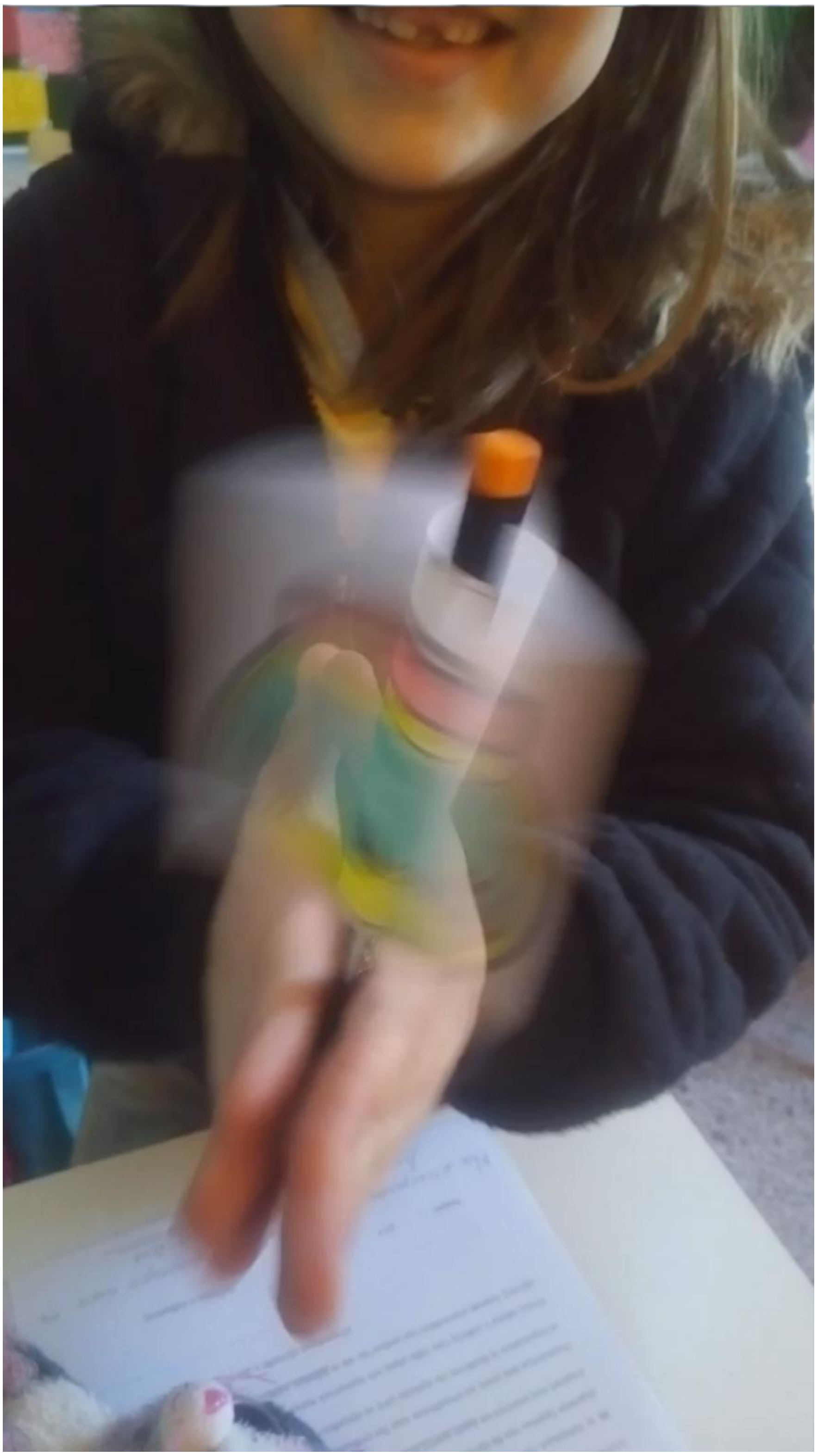
In this way children developed their own "clouds" (picture 1), made imaginary voyages to the moon, the Mars and the galaxies, and investigated the properties of the magnets through play (picture 2).

Picture 2. Children constructed simple magnet games. An introductory activity to the LHC magnets complex.

At the same time children were introduced in the world of particles following a playful approach: they used magnified glasses to explore the microcosm, created pieces of art (see pictures 3 - 4 and video), learned about light and photons and created little "moving pictures" (picture 5).

Picture 3. Introduction to particle physics through examining sand grains

Picture 4. Sand grains under the magnifying glass



Picture 5. Exploring optics with first graders

The educational intervention at the upper grades followed both a content- and process-driven approach. Initially, children inspired by the Big Bang and the world of particles, created many crafts using the power of their imagination (pictures 6 – 9). Special educational material has been developed in order to support pupils during the process. Samples of the educational material can be found here and here. They also explored aquaponics systems as a means of sustaining life during planet and exoplanet colonization (pictures 10 – 11).

Picture 6. The Big Bang installation created by 6th graders

Picture 7. A Big Bang craft by a 5th grade pupil

Picture 8. The solar system created by 6th graders

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Picture 9. 6th graders imagine and reconstruct the world of particles. For more particle "characters" click here.

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Picture 10. Aquaponics is a self-contained system that can provide astronauts protein and vegetation (see NASA)

Picture 11. Children learn how to perform water quality tests

Picture 12. 6th graders remove part of the aquaponics system gravel to allow for a leakage repair at grow bed 1. Pupils take intensive care of earthworm population, which move cautiously to a safe place until repair is completed.

CERNgineer educational content and activities were aligned with upper grades National Curriculum. Main curriculum modules like the structure of the atom (picture 13), magnetism (picture 14) and optics (picture 15) were used to support the attainment of the project's objectives.

Picture 13. The model of the Helium atom created by a 5th grade student

Picture 14. 6th graders explore magnets and their role in the LHC and in particle detectors

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Picture 15. 6th graders explore properties of light and get acquainted with photons, crystals and the CMS Crystal Calorimeter

Picture 16. CERNgineer challenges engage pupils in designing their own "particle" detectors

For more information about the CERNgineer project, updates and engineer challenge activities visit project blog archives: http://www.1dimrafin.com/blog/tag/CERN

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7 Assessment

80 pupils of grades 5 and 6 participated to the CERN pre-servey and completed the on-line questionnaire.

Short term gained knowledge is assessed at the end of each session through engineering artifacts, questions and the student presentations.

Evaluation of the activity will also be completed using the evaluation procedures decided by the Creations project team.

8 Possible Extension

9 References

Beatty, A. (2011). *Successful STEM Education: A Workshop Summary.* National Academies Press.

Pending article: Physics Education "Particle Physics for Primary Schools – enthusing future Physicists" by Pavlidou Maria, Lazzeroni Cristina
Article reference: PED-100750