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Report with general recommendations for educational activities in school at EU level

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Table of content

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Introduction

This deliverable deals with the organization and implementation of the main educational action of the Project, i.e., delivering lessons – lectures, workshops and laboratories in primary and secondary schools in 5 countries involved in the Project.

The educational action started in preliminary form already in September 2019 (introductive, plenary lesson with experiments at UMK for schools involved in Poland), in parallel with perfecting the educational material.

In January 2020 approximately 35-45% of activities performed, with percentages varying between the five countries involved. This allowed to report the preliminary educational outcome.

The main reason for the present report is to identify difficulties and/or lacunas in the practical implementations of narrative teaching and contents in subjects of energy, environment and hydrogen.

We repeat in this report some of the most important point from the first report and concentrate on showing precise scenarios to be followed at EU level, in different educational activities.

However, the report D3.3 in date 30/06/2020 is to be considered an integral part of the present one, as we do not repeat details of teaching time-table, division of tasks, national priorities, additional educational material etc.

The heuristic, social goal is not to teach particular notions of any scientific area (physics, engineering) but stimulate interdisciplinary abilities and induce the social awareness on the necessity of introducing hydrogen technologies.

Deviations

The deliverable was submitted in time, with no deviations occurring.

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1. Planned Activities

This deliverable deals with planned and implemented educational action in the subject of energy and hydrogen fuel cells. To achieve this goal, specific scenarios have been prepared, depending on pupils' age and the country.

1.1 Schools planned

In the Proposal (and the Project approved in December 2018, table 2, p. 135) we planned activities in 42 classes: 16 in Italy, 2 in Switzerland, 4 in Denmark, 16 in Poland and 4 in Germany. Group ages were scheduled as follow: 8-10 yrs old - 15 classes; 11-14 yrs old – 14 classes, 14-18 yrs old – 13 classes. In total, 900 pupils were planned to be involved in the educational path.

1.2 Schools involved

The list of involved schools and the status of lessons delivered before date 20.02.2020 (first run of testing) was as follows:

1) Italy (UNIMORE, UNIBZ)
1a. (UNIBZ) Bolzano node:
Lessons delivered in December 2019:
- Primary school "Langer", 1 class, 25 students, 2 x 2 hours lesson (expert)
- Lower Secondary school "Fermi", 2 classes, 50 students, 2 x 2 hours lesson (expert).

Lessons delivered in January – February 2020:
- Primary school "Langer", 1 class, 25 students, 2 x 2 hours lesson (expert)
- Primary school "Don Bosco", 1 class, 25 students, 4 x 2 hours lesson (expert)
- Primary school "Alighieri", 2 classes, 40 students, 3 x 2 hours lesson (external expert)
- Primary school "Chini", 1 class, 20 students, 3 x 2 hours lesson (external expert)
- Lower Secondary school "Fermi", 2 classes, 50 students, 2 x 2 hours lesson (expert)
- Upper Secondary school "Torricelli", 2 classes, 50 students, 2 x 2 hours lesson (expert)

1b. (UNIMORE) Modena node:
Lessons delivered in December 2019
- Primary school D. D. 1 Formigine: 2 classes, 38 students involved, 4 x 2 hours lesson (expert);
- Lower Secondary school Distretto Didattico "A. Fiori" Formigine: 2 classes and 44 students involved, 4 x 2 hours lesson (expert).

Lessons delivered in January – February 2020:
- Primary school D. D. 1 Formigine: 2 classes, 47 students involved, 4 x 2 hours lesson (expert) in one class, with the last two hours made as online lessons during the lockdown;
- Lower Secondary school Distretto Didattico "A. Fiori" Formigine: 2 classes (1 Magreta, 1 Casinalbo), 46 students involved, 2 x 2 hours lesson (expert) in one class (Magreta), the last two lessons were cancelled due to the lockdown, 3 x 2 hours lesson (expert) in the other one (Casinalbo), with the last two hours made as online lessons during the lockdown.

2) Switzerland (ZHAW) (lessons delivered in January 2020)
- Primarschule Altstadt/Lind (4th grade, about 25 pupils)
- Primarschule Männedorf (1 class 1st grade, 2 classes 2nd grade, two classes 3rd grade)

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3) Germany (agado – Steinbeis 2i) (lessons delivered in January 2020)
- Grandschule Haag-Wolkar, 4th class, 22 pupils
- Werner-Egk-Grandschule Augsburg, 4th class, inclusion school, 23 pupils
- Montessorischule Olympiapark. 3rd and 4th class, 14 pupils
- Alexander von Humboldt Realschule Bayreuth, approx. 20 pupil
- Freie Aton Schule München, 4th and 5th class, approx. 30 pupils

The detailed list of lessons and themes done as in the date June 17th 2020 was given in D3.3. Report.

4) Denmark (DTU) – activities done in September 2020
- Tømmerup Fri- og Efterskole, School providing an extra year after the 10-year primary school: 3 classes involved, ca. 70 students, 3 teachers, 1 x 2 hours in class
- Roskilde Gymnasium, High school: 1 class, 20 students, 1 teacher, 1 x 2 hours in class
- Klostermarksskolen, High school: 1 class, 20 students, 2 teachers, 1 x 4 hours class and practical activities

5) Poland (UMK)
The list of schools which signed the agreements (with institutional links), the dates of the lessons, names of teachers and experts is under address: http://fchgo.fizyka.umk.pl/lekcje/ That page gives also the names of experts and teachers, and dates of the lessons done.
On the site "dydaktyka.fizyka.umk.pl" each school has a separate page assigned to the report of activities. The list below contains the links to these pages:

Primary schools (7th grade, 13 yrs old)
SP Dąbrowa Biskupia (2 classes, 29 pupils)
SP, Strzelno (3 classes, 48 pupils)
SP nr 2, Brusy (3 classes, 62 pupils)
SP, Grupa (2 classes, 50 pupils)
SP, Mikołajki Pomorskie (2 classes, 28 pupils)
SP nr 13, Bydgoszcz, ZS nr 29 (2 classes, 37 pupils)
SP nr 12, Bydgoszcz (2 classes, 31 pupils)
SP, Kowalewo Pomorskie (1 class, 27 pupils)
SP Prabuty (1 class, 17 pupils)

Secondary schools (14 & 15yrs old)
General-purpose high schools (Lyceum)
LO nr 1, Kwidzyn (5 classes, 107 pupils)
LO nr 6, Toruń (2 classes, 57 pupils)
LO nr 1, Gniezno (2 classes, 58 pupils)
ZSO nr 2, Kwidzyn, LO nr 2 (2 classes, 54 pupils)
LA, Słupsk, I LO (1 class, 25 pupils)
IX LO Gdynia (3 classes, 63 pupils)
ZSO nr 3, Bydgoszcz (1 class, 32 pupils)
IV LO, Słupsk (1 class, 15 pupils)
LO nr 2, Kwidzyn (2 classes, 46 pupils)

Technical high schools: electricity and informatics
ZSElektr, Włocławek (1 class, 21 pupils)
ZSE Gdańsk (2 classes, 31 pupils)

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ZST Grudziądz (3 classes, 56 pupils)
Schools without links joined the Project in September (i.e. after the deadline we fixed for the formal agreement). In practice, these schools participate on equal footing with others.

2. Extension of Activities

The lock-down in EU from March 2020 made impossible to conclude scenarios and reach the targets groups in some countries. This made necessary:

1) to deviate some activities into on-line teaching (case of Poland)
2) to postpone some activities (case of Denmark)
3) to perform additional teaching in the period September-November 2020 (Poland)
4) to draw conclusions from already done activities (the case of Germany)

However, the extension of activities allowed to widen the overall target group: from 900 planned, 1300 the goal achieved in June 2020, to more than 1500 in December 2020.

The extension of activities allowed also to cross-over different approaches. For instance, activities based on "Energy box" from University of Bolzano were tested in elementary schools in Poland, and some scenarios prepared for secondary schools were applied (in simplified version) to upper grades of the elementary schools.

These extended, cross-over activities comprised following primary schools (SP) in Poland:

- SP Pruszcz (on-line), 6th grade, 9.11.2020/ 16,11.2020/ 23.11.2020, (A. Karbowski, 22 pupils)

- SP Kowalewo Pomorskie (on-line), 6th grade, 10.11.2020/ 17.11.2020/ 24.11.2020 (A. Karbowski, 18 pupils)

- SP Ośniszczewko, 7th grade, 13.11.2020 (K. Wyborska, 15 pupils)

- SP Ośniszczewko, 8th grade. 05.11.2020 (K. Wyborska, 13 pupils)

- SP Ośniszczewko, 6th grade, 11.12.2020 (K. Wyborska, 8 pupils)

- SP Dąbrowa Biskupia, 8th grade, 9.11.2020, (K. Wyborska, 16 pupils)

- SP Dąbrowa Biskupia,7th grade, 17.11.2020, (K. Wyborska, 17 pupils)

- SP Markowice, 2nd and 6th grades, 24.10.2020 (G. Karwasz, 18 + 26 pupils)

- SP Lubawa (on-line), 10.12.2020/ 17.12.2020 (G. Karwasz, 14 pupils)

- SP Mikołajki Pomorskie (on-line), 16.11.2020/ 20.11.2020/ 23.11.2020 (K. Fedus, 20 pupils)

- SP Prabuty (on-line) (on-line) 12.11.2020/ 19.11.2020/ 26.11.2020 (K. Fedus, 20 pupils)

Unfortunately, because of travel restriction it was not possible to perform joined direct teaching experience UNIBZ-UMK that was planned for November 2020. For the same reason (lock-down of UMK premises) the planned for October video registrations of lessons for secondary schools has been postponed. We managed only (in collaboration with InEuropa) to register an interview on climate changes.

The extension of the Project allowed also to organize a 3-day International Seminar at UMK, in great

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part dedicated to environment, energy and hydrogen, with contributions from UNIMORE (Tiziana Altiero, Michele Cesari), UNIBZ (Federico Corni), ZHAW (Hans Fuchs), InEuropa (Flaminia Smorto), UMK (Grzegorz Karwasz, Andrzej Karbowski, Krzysztof Rochowicz, Mikołaj Karawacki) and Polish stakeholders (Bartosz Dawidowicz and Jan Franz from Gdańsk Technical University, Helena Nowakowska from Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdańsk) see programme at http://dydaktyka.fizyka.umk.pl/komputery_2020/program.html

The Seminar gathered (on-line) 85 participants, including 70 teachers and/or students aiming to become teachers and received very good recensions.

Earlier, in November, the FCHgo consortium participated in the word-wide congress on didactics of physics, GIREP, in Malta. Didactical and pedagogical outcomes were presented (K. Wyborska). The presentation is available on-line.

3. Evaluation of activities

3.1 Lower primary school age 2nd-4th grade (ZHAW, Switzerland)

FCHgo Kids lab at ZHAW Winterthur

Dr Elisabeth Dumont is a researcher at ZHAW and Swiss coordinator of FCHgo Project.

The FCHgo educational material in the younger grades were tested by ZHAW in January-April 2020 in two elementary schools: in Winterthur and Männedorf. Different elements of EDPM were tested at different ages, both at lesson and at workshops. We start conclusions from the 4th grade in Winterthur (08/01/2020). The lessons were done at ZHAW premises by dr Elisabeth Dumont and Erwin Hoender, see Fig. 1, and was based on the FCHgo narrative approach.

Fig. 1. Testing FCHgo didactical material in elementary schools: (a) FCHgo lessons for the 4th grade of Altstadt/Linder at Winterthur, 08/01/2020, at ZHAW laboratories. (b) Second step, after watching "Perpetuum mobile" video: naming "spirits"; copper and zinc were added to account for the electrochemical pile; hydrogen and oxygen – to be used with FCH; the green spiral is a rotation.

Lesson started from the movie "Perpetuum Mobile" by M. Deichmann and H. Fuchs, and from the discussion of ghost which appeared there. Children recognized correctly spirits of the electricity, heat, rotation and light, and the names were written on the blackboard, see Fig. 1b.

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Additionally, the spirits related to Volta's pile and hydrogen fuel cells were introduced "zinc", "copper", "hydrogen" and "oxygen", see Fig. 1b. The same spirits appear on the playing cards (see FCHgo educational material on fchgo.eu).
The practical workshop consisted in building a potato battery using zinc and copper plates and potato slices, see Fig. 2. A wire has been welded to zinc plate and a small LED to the copper plate. Children were very happy when after some trials they manage to build a "pile" with potato slices and make the LED lit up.

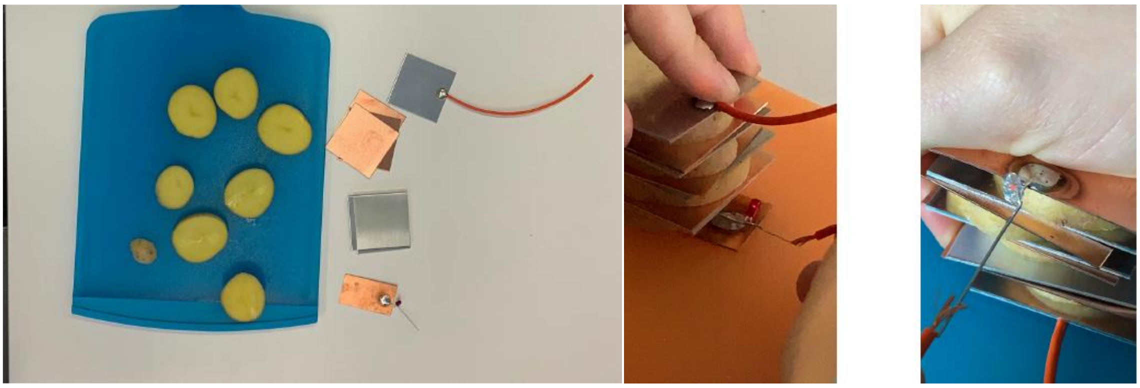

Fig. 2. FCHgo workshop at ZHAW for Winterthur elementary school: building potato battery; (a) material prepared for pupils; (b) & (c) completed construction: that in the middle does not work, as the order of Cu/Zn pairs is mixed; the pile to the right is built correctly and the LED lit up.

Then pupils had been asked to choose from the cards that they received the spirits involved in the energy transformations. They chose correctly four of them (electricity, Zn, Cu, light). So, we were able to summarize the whole chain of energy transformations within two phrases: "Copper and zinc give their energy to the electricity. The electricity gives its energy to the light."

Next step was testing the chain:
photovoltaic cell → electrolysis → hydrogen & oxygen → fuel cell → electrical motor with fan.
Children were given with a model of reversible hydrogen fuel cell. Firstly, they tested the system: solar cell → electrolyser → gas tank (see Fig. 3a) and performed the experiment. Some kids observed that more hydrogen is produced than oxygen.

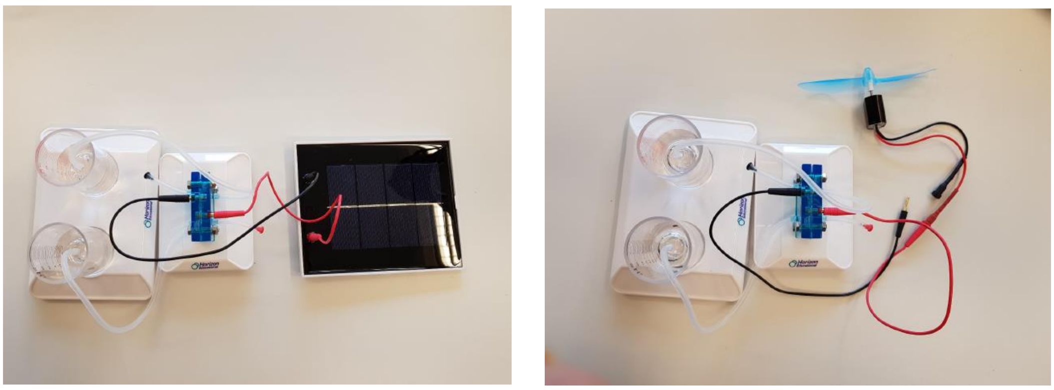

Fig. 3: Experiment at ZHAW for the 4th grade of Winterthur elementary school: (a) electrolysis of water in a reversible fuel hydrogen cell in using "electricity from a photovoltaic panel; (b) using the hydrogen

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and oxygen produced to generate electricity in FCH and supply the current to a small fan. (photo E. Dumont).

After hydrogen and oxygen production, a fan was connected to the fuel cell and the kids observed that the fan rotated as long as there was some gas present in the tanks.

Kids were asked to identify the "ghosts" and tell what they do in the electrolyzer. They said:

1) in the solar cell, light wakes up electricity. In the fuel cell (we used a reversible fuel cell, that worked as an electrolyzer), the electricity produces oxygen and hydrogen out of water.
2) In the fuel cell hydrogen and oxygen make water and they create electricity. Electricity drives the rotation (see the blackboard and the assembling of ghost in fig. 4.)

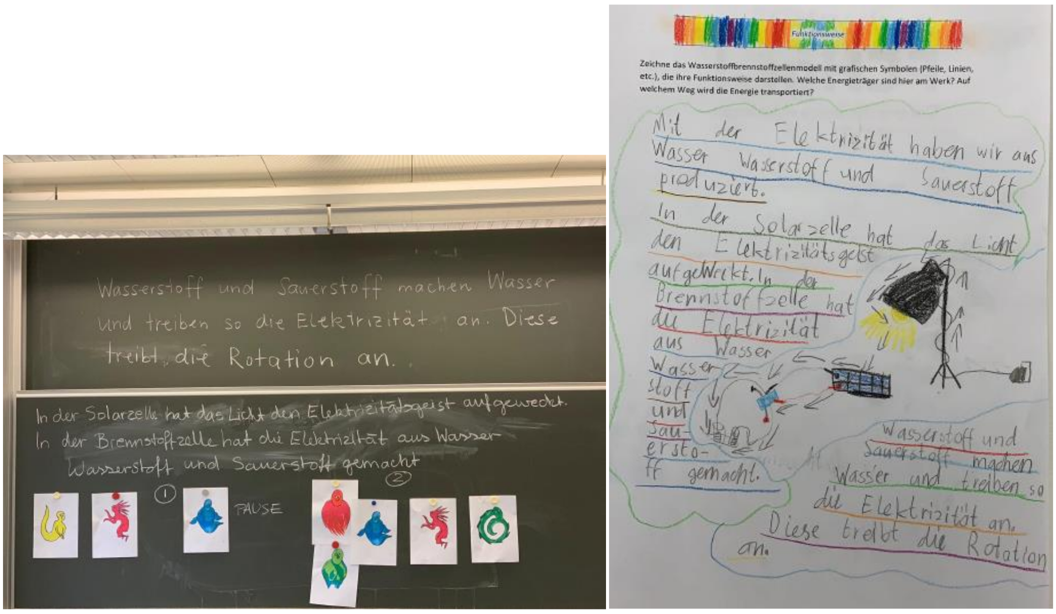

Fig. 4. The didactical outcome of FCHgo lesson on energy transformations and hydrogen fuel cells: (a) summary with "ghost" symbols and two short phrases; (b) report by Lea.

On the summary worksheets we asked: „Draw in which mode the hydrogen fuel cell works? Which kinds of energy is involved? In which way is the energy transported?"

In fig. 4b we present the drawing and answers of Lea. One notes that she used quite advanced expressions: "electrolysis, fuel cell, hydrogen, oxygen, rotation".

The didactical conclusion is clear: apart from the fun in performing the experiment autonomously, the children managed (with the help of "Perpetuum Mobile" video and the "ghosts") to identify (implicitly) different forms of energy.

The narrative (and didactical metaphor) approach turned to be very efficient with such a difficult subject as the chain of energy conversions in hydrogen fuel cells!

Visit of third grade primary school from Männedorf at ZHAW

On January 27th 2020 Ms Janz visited us with his 3rd grade of primary school Männedorf.

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Similar scenarios as with the 4th grade (see above) were applied. From the graphical report below, one understands that even if children were not so precise in acquiring all notions and they used a simpler language – they were able to acquire the fundamental understanding of energy transformations, generating electricity in the electrochemical cell and functioning of the hydrogen fuel cells.

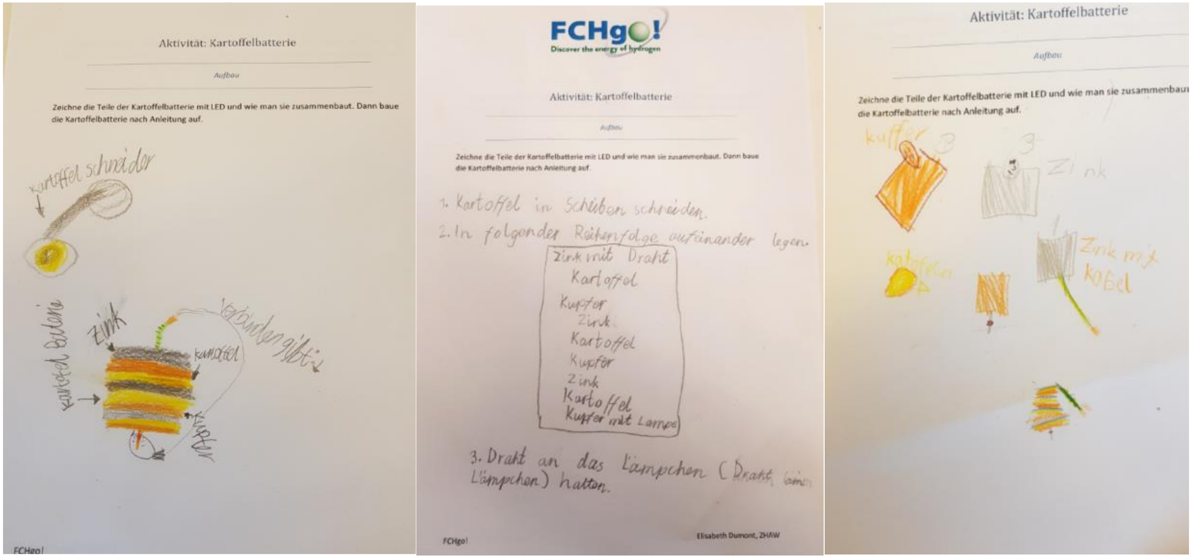

Fig. 5. Workshops at ZHAW (27/02/2020) with 3rd grade elementary school. Worksheet: “Draw the parts of the potato battery with LED and in which manner they are assembled. Make the battery.” Three different representations: (a) a drawing, (b) a description, (c) “ghosts” scheme.

The second worksheet was used to summarize the energy transformations: “Which energy carriers (ghosts, monsters) are at work in solar cells? Which ghosts do sleep at the beginning and must be awaken? Which ghosts are awakened?” Obviously, the questions were chosen to fit conceptually with what children have seen at video. Single answers varied much - from plain text (with no drawings) “The light awakes the electricity. The electricity awakes the rotation.” to mixed text and drawings of Zn and Cu plated (Fig. 6a), schemes of transitions between ghosts (Fig. 6b) and a sheet full of possible ghosts, including water, which was not included into the chain of the photo and hydrogen fuel cells (Fig. 6c). Somebody added: “At the end the heat remains”. Another answer reported hydrogen and oxygen. Obviously, the aim of the lesson was to induce main notions and trigger children’s imagination, not to get scientific precision. So, the answer (b) that both light and the heat creates the electricity is equally fascinating as other reports, see Fig. 6.

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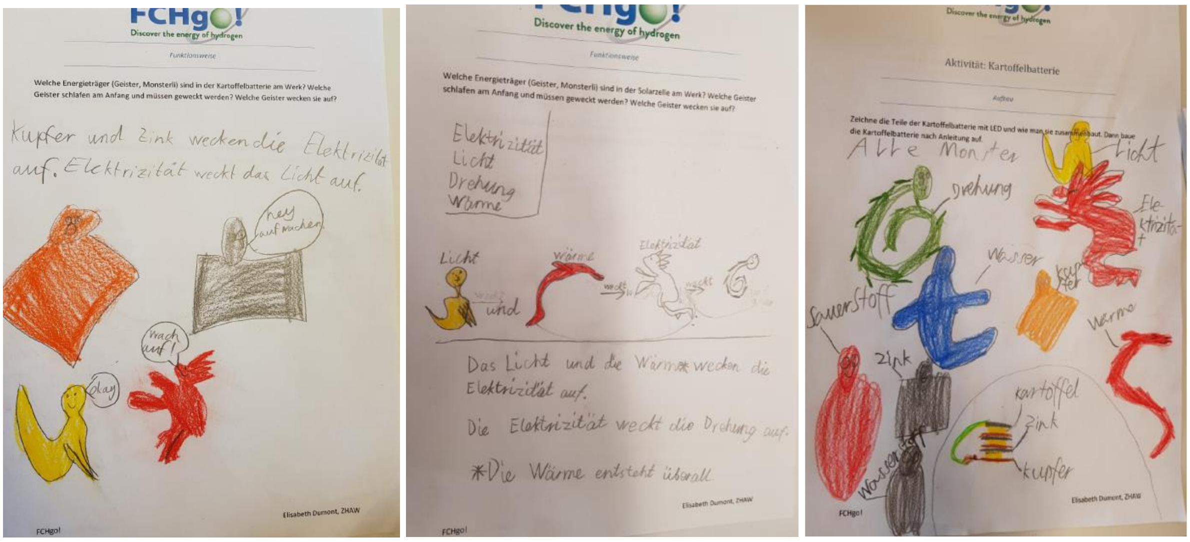

Fig. 6. "Which energy ghosts are involved in the energy transformations?" Descriptions of children are short and use simple words: "Copper and zinc woke up the electricity, Electricity woke up the light." But the answers varied much in forms and contents (see the text for the discussion. Note on (a) that the kid attributed some "personality" to the ghost, saying "OK! I did it."

The third part of the lesson was devoted to experiments with hydrogen fuel cells. Again, we got very individual answers to the question "Show the construction of the FCH assembly". All children reported the schemes correctly, see Fig. 7. Majority reported the experiment with solar cell and the engine (Fig. 7a, b). Some of them surprised us with detailed descriptions, like "fill the tube with distilled water" (Fig. 7c).

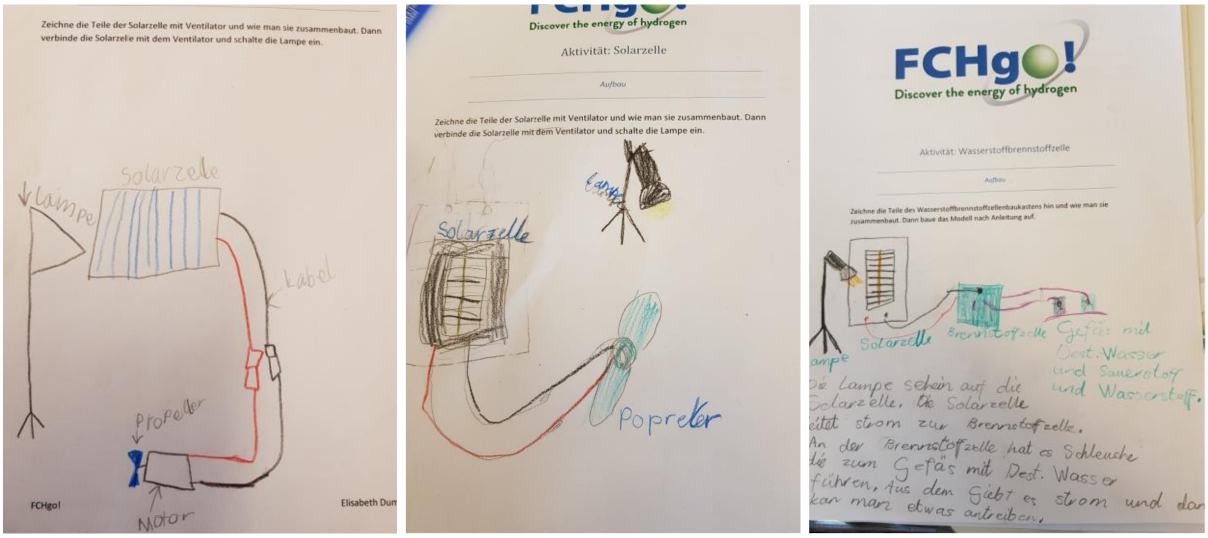

Fig. 7. Reports on experiments with photovoltaic cell and on hydrogen fuel cell.

As in the case of the 4th grade, we conclude that pupils understood the main ideas of the energy transformation and showed much imagination in describing them.

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Visit of second grade primary school Männedorf

The third implementation of FCHgo didactics in ZHAW was the visit of 2nd grade primary school from Männedorf.

The exact scenario was:
1) Prof. Hans Fuchs reads Apple Story to the kids
2) Kids discuss Apple Story
3) Kids make some drawings
4) Hans shows the apple battery to the kids
5) Kids make some drawings
6) Kids make experiments with photovoltaic panel and ventilator
7) Kids make some drawings
8) Hans discusses ghosts (Forces of Nature)
9) Kids play Forces of Nature in photovoltaic panel (light, electricity, wind)
10) Kids draw what they have just played

The lesson was run personally by professor Hans Fuchs, the author of "An Apple Story". The scenario included no "Perpetuum Mobile" video as we retained some concept too difficult for small children. In spite of this, children followed with attention both the very reading of the story and the experiments that followed, see pictures below.

Fig. 8. How one can keep children (and the teacher) involved into a didactical narration? (a) Prof. H. Fuchs reading "An Apple Story" – picturesque description of energy (and matter) transformations. (b) Preparing experiment with Volta's pile using apples slices as electrolytes.

The same experiments as with the 4th grade were performed – this time apple slices were prepared "on spot", see Fig. 8b. With no ghosts involved, the reports of children on the "apple battery" were less picturesque than in previous examples, but were equally precise from the technical point of view, Fig. 9a. Next experiment was with the photovoltaic cell supplying the fan, see drawing in Fig. 9b.

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Fig. 9 Two reports from the experiment in 2nd grade Männedorf school (a) Apple battery: note a slice of apple to be inserted between Zn and Cu plates; (b) photovoltaic cell connected to a fan.

The novel element tested in the 2nd grade was the interactive play with transfers of energy: children acted as energy carriers and pass the energy portions one to another, see Fig. 10. Some of the children reported the play as a description (Fig. 10b) and some of them recalled the concept of "ghosts", see Fig. 11.

Fig. 10. Testing FCHgo in 2nd grade elementary school in Männedorf: interactive play with energy carriers (a) and an example of the descriptive report of this activity (compare experiment in Fig. 11b).

Fig. 11. Two different representations of the interactive play in energy carriers – the proof that kids acquire concepts not mere pictures of the play. They also include explanations for any non-experts.

Resuming the experience with really young (8 yrs old) children – they followed with interest the narration in "Apple Story", they liked constructing of the apple-battery and the interactive play in

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energy carriers. By comparing with 3rd and 4th grade we conclude that teaching concepts of energy transformations, electricity, photovoltaic cells etc. is just on the limit of age in the 2nd grade. Children use their imagination but possibilities of teaching more details that would require FCH subjects are still limited in this age.

The teacher reported the impressions of children in a letter (see the text below). The final interactive play (energy transfer) was particularly joyful (see Fig. 12) and finished in with a general enthusiasm.

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It was an instructive and interesting excursion with you in the energy-lab! Many thanks to both of you for your commitment to elucidate these invisible processes to the children in a manner appropriate to their age. The story with the apple was a successful introduction to the topic.

In retrospect I would limit the visit to two hours. At eleven o'clock some of the children were exhausted. They might have liked to continue to play for longer time, but back in the classroom their energy dropped. Two of the children were still recovering from a longer illness, but they absolutely wanted to part in the excursion.

Some other children could not sleep in the night before, because of the strong storm or of too much excitement. However, the game with confetti waked up everybody and the children became high-spirited.
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Fig. 12. Photos from the letter of Mrs Verena Bucher, teacher in Männedorf elementary school. Unfortunately, it was the last lesson that we manage to organize before the COVID-19 lock-down.

3.2 Primary and middle schools (UNIMORE)

Didactical activities and remarks by teachers and UNIMORE expert

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3.2.1 Primary School “Ferrari”, Formigine, Modena

Class 5D

Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video was not filmed because no waivers of responsibility were produced. The video should have been filmed by the teacher at the end of February.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.

Class 5G

Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video was filmed with only some of the pupils, because not everybody produced waivers of responsibility. All pupils alternated during the dramatization, but only the group of pupils that produced waivers was filmed.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.

Class 5I

Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video was not filmed because no waivers of responsibility were produced. The video should have been filmed by the teacher at the end of February. The pupils have also produced a poem and rap song about energy.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.

3.2.2 Primary School “Carducci”, Formigine, Modena

Class 5C

Variation on the lessons and activities plan (and why):

- In the second meeting a colleague of the teacher was present.

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- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.
- The last meeting (Analysis of Toys/Models) was performed online due to the COVID-19 school lockdown.

3.2.3 Lower Secondary School "Fiori", Formigine, Modena

Class 3D

Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video was performed during the 4th meeting, as the 3rd meeting required more time to reflect upon the Perpetuum Mobile video.
- The objectives of the 4th meeting “Cyclic and reversible processes, the role of entropy” and “Other analogies or comparisons: with or without accumulation, electricity as input or output, energy exchangers are reversible or not” were not performed due to lack of time.
- Energy diagrams were proposed already since the second meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.

Class 3H

Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video was not filmed because the activity was not led by teacher between 3rd and 4th meetings. The expert has recovered the role-playing activity during the 4th meeting, in order to allow the pupils to experience this useful activity.
- The objectives of the 4th meeting “Cyclic and reversible processes, the role of entropy” and “Other analogies or comparisons: with or without accumulation, electricity as input or output, energy exchangers are reversible or not” were not performed due to lack of time.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.

3.2.4 Lower Secondary School S.M.S. “A. Fiori”, Casinalbo, Modena

Class 3M

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Variation on the lessons and activities plan (and why):

- The Fuel Cell hydrogen car has been presented during the third meeting with the expert because more time for observations and analysis was needed.
- The role-playing video, the objectives of the 4th meeting “Cyclic and reversible processes, the role of entropy” and “Other analogies or comparisons: with or without accumulation, electricity as input or output, energy exchangers are reversible or not” were not deeply analysed due to the COVID-19 school lockdown.
- Energy diagrams were proposed already since the 2nd meeting to have an easier understanding of energy carriers and exchangers. The diagrams were written in a more complex manner with each meeting.
- The analysis of Toys/Models was performed online by sending a video of a recorded lesson.
- The energy narrative lesson was not performed in school due to the COVID-19 school lockdown, but it was assigned as homework assignment.

1st meeting:

No variations.

The ‘Apple Story’ reading has been performed together with the analysis of verbal and iconic language. The estimated times were slightly underrated, because the lesson is not classroom-taught and the pupils need to speak, discuss and question, being an active part of the reading.

Material and language are not properly adequate for older pupils, they should be reworked for a higher level. The involvement and participation of pupils are adequate mainly because the class has a serious and diligent attitude, with a high respect of school rules.

2nd meeting:

The activities were performed as outlined in project’s educational path. Modelling and dramatization of objects were introduced in order to facilitate the understanding of energy carriers and exchangers. Utilised examples were initially very simple, and then they were completed and deepened during the lesson. The pupils were diligent and prepared; therefore, it was possible to deepen their knowledge introducing basic physics and chemistry concepts. The use of diagrams was useful in order to discuss with pupils on the concept of carried and transferred energy.

The pupils’ work takes one hour and it has been performed by dividing the kids into 5-6 groups. The real time of work is a longer than expected because of logistical reasons and because the treated topic is rich and elaborate.

The introduction of carriers and exchangers has requested a longer time than expected and it must involve dramatization in order to allow a good understanding. The explanation of card games and their examples have overestimated: the pupils understand the rules in 5 minutes and each game lasts for 5-10 minutes.

The materials are adequate, except the dynamo torch that, being a crank flashlight, can lead the pupils to different considerations, due to its name. It should be better to find an object with

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a name that reflects its real functioning. The cards should be printed in a smaller format (as I did) in order to allow pupils to play in the school time breaks. However, the card game longevity seems not very high.

3rd meeting:

The activities were performed as outlined in project's educational path, with the exception of the role-playing activity, because the fuel cell car activity took longer time due to the large number of questions by students. Therefore, I have decided to introduce the fuel cell car observation and its worksheet at the start of the lesson, in order to verify the pupils' ability of observation and to have a feedback on their understanding of energy carriers and exchangers. The activities were performed using alternate groups: some pupils worked on the fuel cell hydrogen car, while others watched FCHgo movies on Hydrogen technology. This has allowed to work on the fuel cell car model with smaller groups.

The observation of the toy models has been performed with three groups, because there were 3 model cars. The compilation of the worksheet has been performed with all the class together, giving to each pupil a different task. The observation and consideration take about 45 minutes.

The materials are adequate, but it should be better to have 5-6 model cars in order to facilitate the observations and considerations in smaller groups.

3.2.5 Remarks by Teachers

Primary School "Ferrari", Formigine, Modena

Classes 5D & 5I

- In general, how do you rate the entire educational process? Very good.
- Which critical elements need to be addressed? The Apple story is not very engaging.
- State your opinion about the disciplinary contents. Very good.
- State your opinion about the methodological contents. Very good.

Other thoughts? None

Class 5G

- In general, how do you rate the entire educational process? Excellent.
- Which critical elements need to be addressed? Perhaps too few times. For pupils' questions at the end of each meeting.
- State your opinion about the disciplinary contents. Coherent.
- State your opinion about the methodological contents. Adequate.

Other thoughts? None

Secondary School of 1st grade "A. Fiori", Formigine, Modena

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Class 3H

- In general, how do you rate the entire educational process? The process required too much time and it was overall superficial for secondary school classes.
- Which critical elements need to be addressed? Not adequate for the pupils' age. It is more useful for primary schools.
- State your opinion about the disciplinary contents. Few and superficial.
- State your opinion about the methodological contents. Too few experimentations. Too much fear to use a more complex scientific language.

Other thoughts? Contents, methods and language should be calibrated to the pupils and to the scientific objective to reach.

Secondary School of 1st grade S.M.S. "A. Fiori", Casinalbo, Modena

Class 3M

- In general, how do you rate the entire educational process? Very interesting and useful to have a discussion with pupils on current events.
- Which critical elements need to be addressed? None.
- State your opinion about the disciplinary contents. The contents are in line with the program of technology and science and they allowed to deepen some concepts.
- State your opinion about the methodological contents. Used methodology was very attractive for pupils.
- Other thoughts? It should have been better to have more fuel cell model cars, so that every group had one.

- In general, how do you rate the entire educational process? Very useful and easily understandable by pupils, even though complex concepts and themes were treated.
- Which critical elements need to be addressed? I think that the project is effective and it is easily integrated with our program of science and technology, where we have previously taught some concepts of electricity and magnetism, and therefore we have introduced some terms that also used in the project.
- State your opinion about the disciplinary contents. The educational path integrates perfectly with the program of science and technology of the third year of Secondary School of the 1st grade, and it offers a deepening of some concepts that previously could not be grasped by the pupils.

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- State your opinion about the methodological contents. The used methodology is surely very involving. The activities alternate short theoretical parts with lab experiences and group work. The videos length is adequate and they are very clear. We had organised a visit to a Hydro electrical power plant in Riva del Garda, which could have helped to reinforce some concepts. Unfortunately, it could not be carried out to the Coronavirus lockdown.
- Other thoughts? Regarding the lesson with the fuel cell car, if possible, each group should have one car to assemble and explore (in our case, the groups were 6, and we had 3 model cars). I would devote more time to the explanation of the functioning of the car. This is because I teach in the third year of Secondary School of the 1st grade, and many pupils then go to Technical or to Applied Sciences Institutes, and therefore they have a high motivation and involved personal interests. Moreover, many of them already have the prerequisites to understand the fuel cell car functioning.

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3.2.6 Evaluation of UNIMORE activities

Interest and involvement of students in scientific disciplines (1: little useful; 5: very useful).

	Total	Primary School	Secondary School
Meeting 1			
1. "Apple story" reading	3.46 ± 1.39	3.57	3.33
2. Analysis of verbal and non-verbal language	3.38 ± 1.26	3.86	2.83
3. Explanation of the "Toy Guide"	4.31 ± 0.48	4.29	4.33
Between Meeting 1 and Meeting 2			
1. Exploration of the Toys	4.15 ± 0.55	4.14	4.17
2. Finishing the analysis of the language of the "Apple story"	3.33 ± 1.37	3.67	3.00
Meeting 2			
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	4.15 ± 1.34	4.86	3.33
2. Introduction of carriers	4.23 ± 0.83	4.57	3.83
3. Card Games: "Find the exchanger" and "Find the Carrier"	3.92 ± 1.19	4.43	3.33
Between Meeting 2 and Meeting 3			
1. Exploration of other Toys brought by pupils	3.92 ± 1.00	4.00	3.80
2. Watch the movie "Perpetuum mobile"	4.23 ± 1.17	4.86	3.50
3. Write "Stories of the Dynamics" of different toys	3.73 ± 1.01	3.57	4.00
Meeting 3			
1. Planning and writing of the storyboard of Role playing	3.92 ± 1.24	4.29	3.40
2. First rehearsals of the Role playing	3.80 ± 1.32	4.33	3.00
Between Meeting 3 and Meeting 4			
1. Performing of the Role playing	4.10 ± 1.20	4.29	3.67
2. Filming the Role playing	3.71 ± 1.25	4.00	3.00
Meeting 4: fuel cell car			
1. Comparing stories of the dynamics of a toy ("Rechargeable flashlight" and "Fuel cell car")	4.27 ± 0.79	4.50	4.00
2. Drawing the *Energy Diagrams* for both toys	3.92 ± 0.79	4.00	3.83
3. Evidence the analogies between the two toys ("Rechargeable flashlight" and "Fuel cell car")	4.00 ± 0.77	4.17	3.80
(for older pupils)			
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	4.00 ± 1.41	4.00	4.00
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	3.57 ± 1.13	4.00	3.50

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<u>Knowledge and understanding of the contents</u> (1: little useful; 5: very useful).

	Total	Primary School	Secondary School
Meeting 1			
1. "Apple story" reading	3.62 ± 1.04	3.71	3.50
2. Analysis of verbal and non-verbal language	3.62 ± 0.87	4.00	3.17
3. Explanation of the "Toy Guide"	4.08 ± 0.76	4.29	3.83
Between Meeting 1 and Meeting 2			
1. Exploration of the Toys	4.15 ± 0.8	4.43	3.83
2. Finishing the analysis of the language of the "Apple story"	4.40 ± 1.37	4.33	3.00
Meeting 2			
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	4.00 ± 0.71	4.14	3.83
2. Introduction of carriers	4.00 ± 0.58	4.00	4.00
3. Card Games: "Find the exchanger" and "Find the Carrier"	3.85 ± 0.69	4.00	3.67
Between Meeting 2 and Meeting 3			
1. Exploration of other Toys brought by pupils	3.83 ± 0.72	3.71	4.00
2. Watch the movie "Perpetuum mobile"	3.85 ± 1.21	4.29	3.33
3. Write "Stories of the Dynamics" of different toys	3.82 ± 0.75	3.71	4.00
Meeting 3			
1. Planning and writing of the storyboard of Role playing	3.67 ± 0.98	4.00	3.20
2. First rehearsals of the Role playing	3.67 ± 0.98	4.00	3.20
Between Meeting 3 and Meeting 4			
1. Performing of the Role playing	3.82 ± 1.08	4.00	3.50
2. Filming the Role playing	3.57 ± 1.13	4.00	2.50
Meeting 4: fuel cell car			
1. Comparing stories of the dynamics of a toy ("Rechargeable flashlight" and "Fuel cell car")	3.82 ± 0.60	4.17	3.40
2. Drawing the *Energy Diagrams* for both toys	3.82 ± 0.75	3.83	3.80
3. Evidence the analogies between the two toys ("Rechargeable flashlight" and "Fuel cell car")	3.82 ± 0.98	4.00	3.60
(for older pupils)			
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	5.00 ± 0.00	5.00	5.00
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	4.00 ± 1.10	5.00	3.80

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Use of scientific thinking based on analogies and metaphors (1: little useful; 5: very useful).

	Total	Primary School	Secondary School
Meeting 1			
1. “Apple story” reading	3.46 ± 1.2	3.43	3.50
2. Analysis of verbal and non verbal language	3.62 ± 0.87	4.00	3.17
3. Explanation of the “Toy Guide”	3.69 ± 1.03	3.71	3.67
Between Meeting 1 and Meeting 2			
1. Exploration of the Toys	3.69 ± 1.18	3.86	3.50
2. Finishing the analysis of the language of the “Apple story”	3.17 ± 1.17	3.33	3.00
Meeting 2			
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	3.54 ± 1.05	3.57	3.50
2. Introduction of carriers	3.69 ± 1.03	3.71	3.67
3. Card Games: “Find the exchanger” and “Find the Carrier”	3.62 ± 1.04	3.71	3.50
Between Meeting 2 and Meeting 3			
1. Exploration of other Toys brought by pupils	3.50 ± 0.90	3.29	3.80
2. Watch the movie “Perpetuum mobile”	4.00 ± 1.15	4.43	3.50
3. Write “Stories of the Dynamics” of different toys	3.27 ± 1.19	3.00	3.75
Meeting 3			
1. Planning and writing of the storyboard of Role playing	3.75 ± 1.06	4.00	3.40
2. First rehearsals of the Role playing	3.27 ± 1.19	4.00	3.20
Between Meeting 3 and Meeting 4			
1. Performing of the Role playing	3.82 ± 1.08	4.00	3.50
2. Filming the Role playing	3.57 ± 1.13	4.00	2.50
Meeting 4: fuel cell car			
1. Comparing stories of the dynamics of a toy (“Rechargeable flashlight” and “Fuel cell car”)	4.00 ± 1.10	4.33	3.60
2. Drawing the *Energy Diagrams* for both toys	3.91 ± 0.83	4.33	3.40
3. Evidence the analogies between the two toys (“Rechargeable flashlight” and “Fuel cell car”)	4.09 ± 0.94	4.33	3.80
(for older pupils)			
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	5.00 ± 0.00	5.00	5.00
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	4.00 ± 1.10	5.00	3.80

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Ability of discussion and collaboration among students (1: little useful; 5: very useful).

	Total	Primary School	Secondary School
Meeting 1			
1. “Apple story” reading	2.62 ± 1.19	2.71	2.50
2. Analysis of verbal and non verbal language	2.85 ± 1.14	3.14	2.50
3. Explanation of the “Toy Guide”	3.38 ± 0.96	3.57	3.17
Between Meeting 1 and Meeting 2			
1. Exploration of the Toys	4.00 ± 0.71	4.14	3.83
2. Finishing the analysis of the language of the “Apple story”	3.33 ± 1.37	3.67	3.00
Meeting 2			
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	3.77 ± 0.44	4.00	3.50
2. Introduction of carriers	3.85 ± 0.55	4.14	3.50
3. Card Games: “Find the exchanger” and “Find the Carrier”	3.77 ± 1.01	4.00	3.50
Between Meeting 2 and Meeting 3			
1. Exploration of other Toys brought by pupils	3.92 ± 0.79	4.00	3.80
2. Watch the movie “Perpetuum mobile”	3.31 ± 1.49	3.71	2.83
3. Write “Stories of the Dynamics” of different toys	3.91 ± 0.94	4.00	3.75
Meeting 3			
1. Planning and writing of the storyboard of Role playing	3.75 ± 1.06	4.00	3.40
2. First rehearsals of the Role playing	3.75 ± 1.06	4.29	3.00
Between Meeting 3 and Meeting 4			
1. Performing of the Role playing	4.09 ± 1.22	4.43	3.50
2. Filming the Role playing	4.00 ± 1.55	4.50	3.00
Meeting 4: fuel cell car			
1. Comparing stories of the dynamics of a toy (“Rechargeable flashlight” and “Fuel cell car”)	3.82 ± 0.98	4.00	3.60
2. Drawing the *Energy Diagrams* for both toys	3.82 ± 0.98	4.00	3.60
3. Evidence the analogies between the two toys (“Rechargeable flashlight” and “Fuel cell car”)	3.64 ± 1.03	3.67	3.60
(for older pupils)			
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	4.67 ± 0.58	4.00	5.00
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	3.67 ± 1.21	4.00	3.60

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3.2.7 Timetable of UNIMORE school activities

School	Class	no. of pupils	Meetings (2 hours/each)	Lessons mode
Primary School (6-10 yo)				
Carducci Formigine	5C	24	1) 13/01/2020 2) 24/01/2020 3) 10/02/2020 4) 24/02/2020	presence presence presence online
Ferrari Formigine	5G	23	1) 15/01/2020 2) 22/01/2020 3) 29/01/2020 4) 05/02/2020	presence presence presence presence
Ferrari Formigine	5I	20	1) 28/11/2019 2) 03/12/2019 3) 12/12/2019 4) 19/12/2019	presence presence presence presence
Ferrari Formigine	5D	18	1) 28/11/2019 2) 03/12/2019 3) 12/12/2019 4) 19/12/2019	presence presence presence presence
Lower Secondary School (11-13 yo)				
Medie Fiori Formigine	3H	22	1) 02/12/2019 2) 06/12/2019 3) 13/12/2019 4) 20/12/2019	presence presence presence presence
Medie Fiori	3D	22	1) 26/11/2019 2) 02/12/2019 3) 10/12/2019 4) 16/12/2019	presence presence presence presence

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Medie Magreta	3P*	20	1) 27/01/2020 2) 07/02/2020 3) 17/02/2020 4) 22/02/2020 5) 05/2020 6) 05/2020	presence presence presence presence online online
Medie Casinalbo	3M	26	1) 04/02/2020 2) 11/02/2020 3) 20/02/2020 4) 25/02/2020	presence presence presence online

*This activity was not considered for the evaluation due to heterogeneity of utilised approaches.

3.3 Primary and middle schools (UNIBZ, Italy) - didactical activities and remarks by teachers and UNIBZ experts

3.3.1 Primary School Class 5 A "LANGER" and 5 D "DON BOSCO"

1st meeting

Activities:

Reading and discussion about the Apple Story (70 min)

Introduction to the toy form (anatomy and physiology)

Free discussion with pupils in groups (though not essential). The expert reads one page at a time. The agreement with pupils is not to use the word "energy", at least until the story itself uses it. It is necessary to instruct the teacher well on anatomy and physiology of the toy, and to give tasks to children in various groups (draftsman, engineer, technician, scientist, writer, ...).

Remarks:

It is useful to help pupils in recognizing the analogies that are present in the story.

Materials: OK

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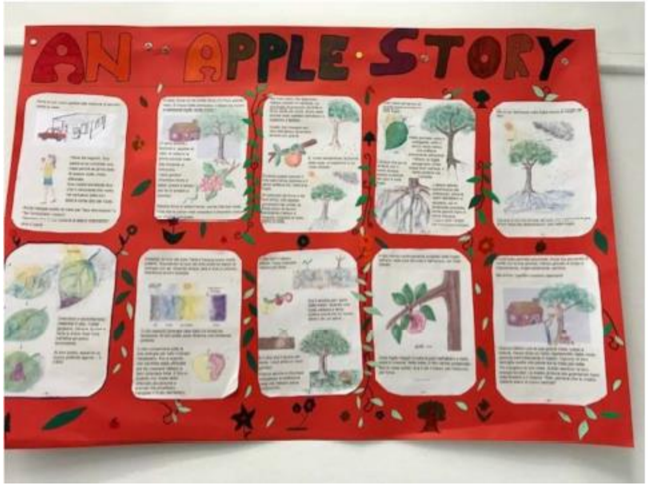

Fig. 13. A poster with An Apple Story.

2nd meeting

Activities:

Groups present anatomy and physiology sheets (60 min).

Introduction to energy carriers and assignment of carriers to different toys (dynamo torch, wind-mill, hydrogen car)

Card games: "Find the exchanger" and "Find the carrier" (ref. Rules card games)

Remarks:

Pupils tend to do only the anatomy and have some difficulties in the physiology.

Pupils were supported in finding the energy carriers. Carriers are introduced one by one and asked by the various groups if they fit in with their toy. A list of the carriers is made for each toy.

It is important to instruct the teacher about the physiology.

There was not enough time for the card games and that activity has been done by the teacher.

Materials: OK

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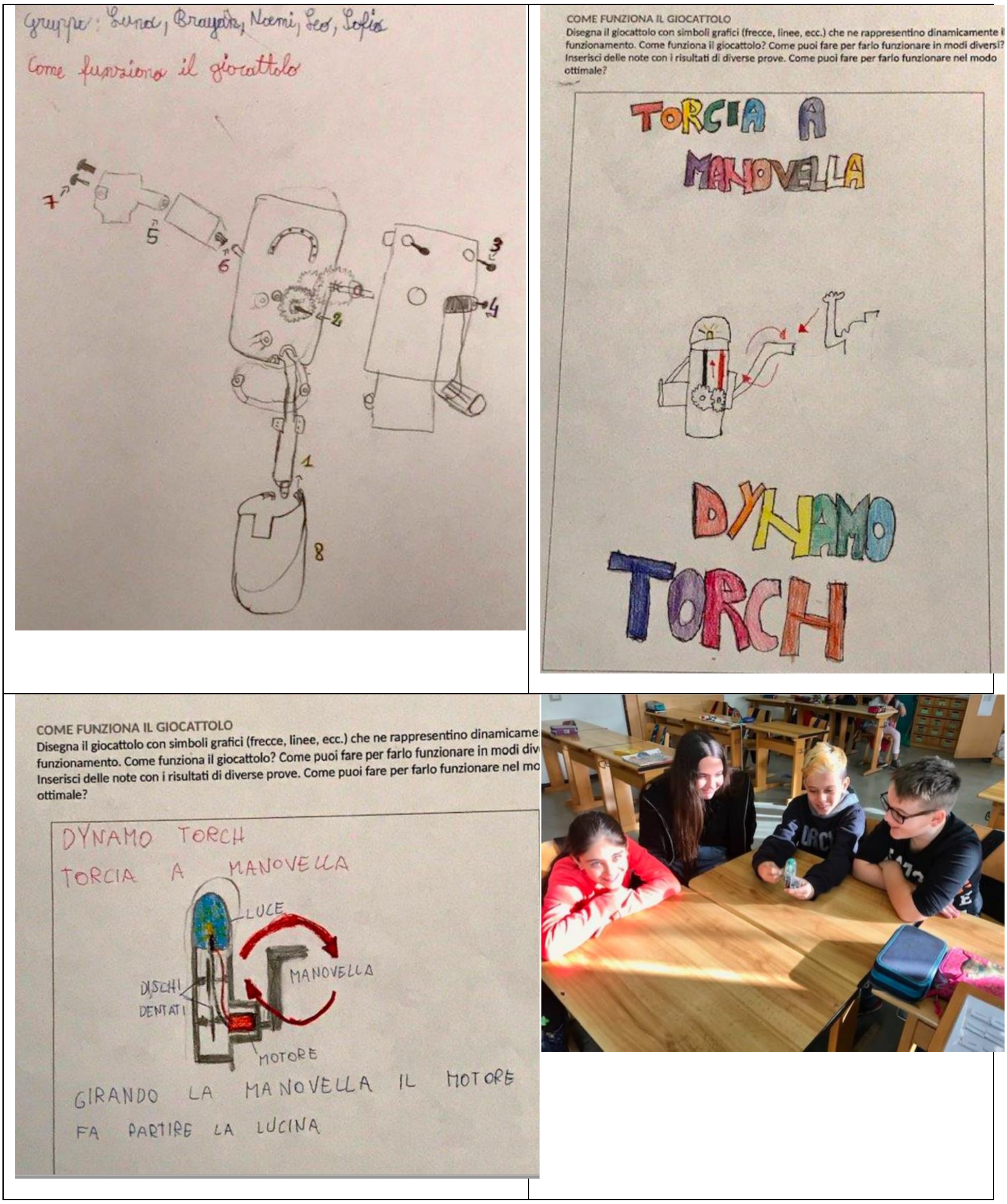

Fig. 14. Reports on experiments with dynamo torch and involved energy carriers.

3rd meeting

Activities:

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Planning and writing of the storyboard for role play of one of the toys, preferably the Hydrogen car (ref. *Role Play Guide*)

First rehearsals of the role play

Remarks:

First, the Perpetuum Mobile movie has been watched (even if it was already seen by the pupils during the week). Concepts emerged: Energy is represented by the yellow powder that the "little monsters" exchange. The "little monsters" are carriers of energy. In each exchange some energy is lost. At the end there is the same amount of energy as there was at the beginning, simply most of it has fallen on the floor. Electricity is not energy, but it carries energy. Same with light, water, and motion. When energy carriers have a lot of energy, they are different from when they have little: electricity is high voltage, light is high intensity, water is high pressure, motion is high speed.

The play has been designed only orally.

Fig. 15 Representation of energy carriers in use (following the FCHgo toolkit).

4th meeting

Activities:

Discussion on the narratives and dramatizations performed by the groups

Drawing of the Energy Diagrams of the two toys (see photos)

Highlighting the similarities between the two toys

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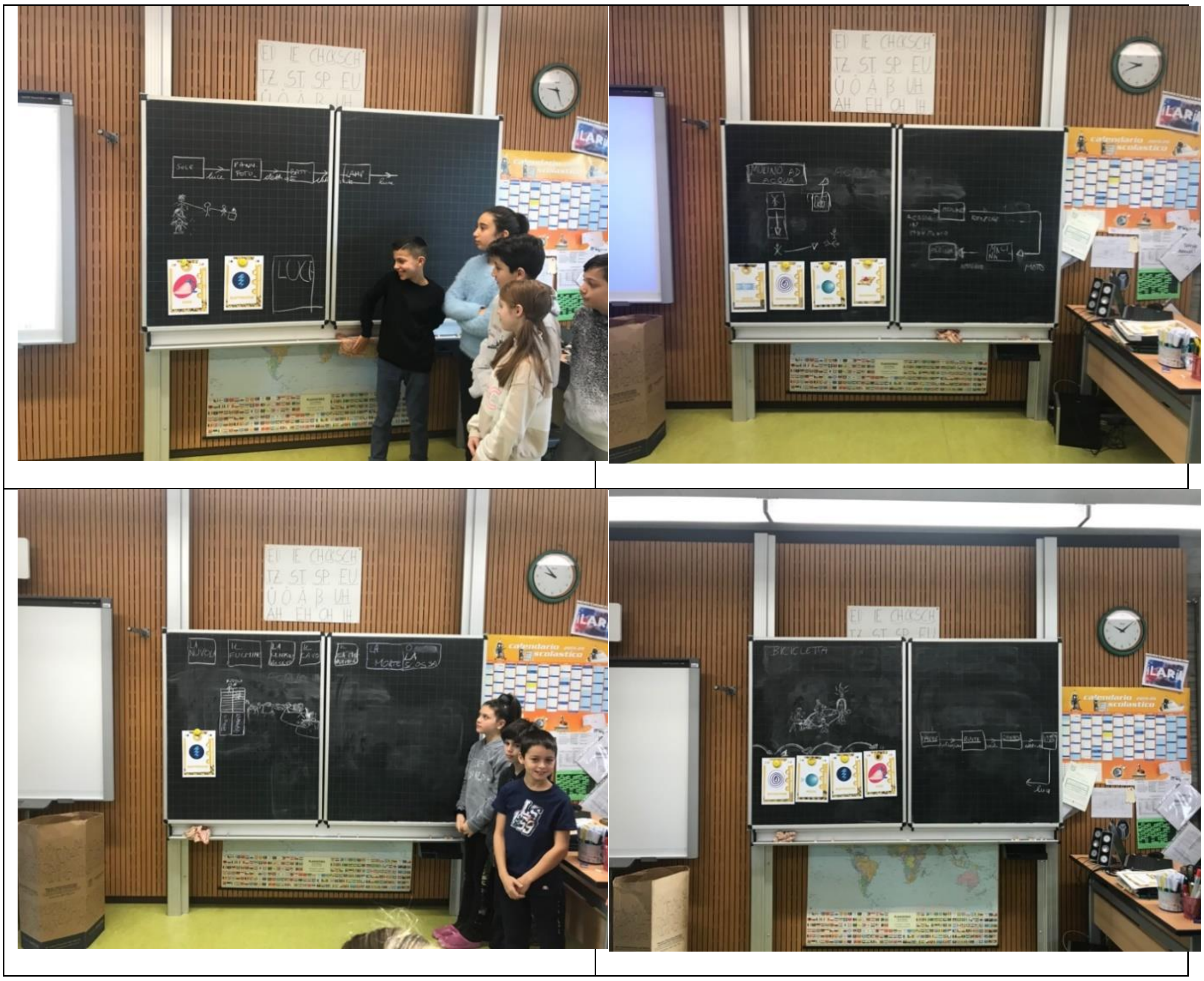

Fig. 16 Children try to find the energy carriers involved in the operation of different systems (devices) including the hydrogen fuel cells.

The school coordinator (dr. Lorella Saccoman) has handed over a report after the interventions. Some relevant paragraphs are reported below.

The teacher of the fifth grade Langer joined the project with enthusiasm, viewed the material provided, and together with the class began the process.

The students were immediately captivated by Prof. Corni's narration, and although the topic is quite complex for elementary school students, the materials used as well as the language chosen, allowed the students to find the right key to develop the planned path.

The materials made available represent the right balance between theoretical aspects and practical activities, they are accompanied by videos and explanatory cards, which allowed students to make their own a number of key concepts, which will be developed during their future studies.

During the project, students have tried to make some videos that, through role playing, representing some of the concepts of energy developed during the course. Having the opportunity to carry out activities through the toys made available, to explore others brought to school from home, to build

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"stories of energy" of the various toys, has allowed them to compare various toys, finding any similarities or differences with respect to the concept of energy used for their operation. An important aspect that is given great importance is the collaborative methodology among peers that is implemented throughout the project with work done in pairs, small groups and general reflections in plenary: all this to make students aware of the importance of collaboration, sharing in a network perspective.

Fundamental is also all the work of reflection and metacognition that the teacher can implement in parallel, thanks to the process of construction of basic concepts during the development of the project.

3.3.2 Primary School "Alighieri" and "Chini" (External expert)

An external volunteer expert (dr. Leonardo Colletti) collaborated with 3 classes in Bolzano. He has been trained with individual meetings and during the training of the teachers. He also attended the meetings of Secondary School.

He handed over the general report below about his activities in the project.

I presented the project in three different intercultural primary school classes (5th grade) with about 20 pupils per class, in Bolzano-Bozen (Italy) in the period January-February 2020. After a preliminary meeting with the teachers, we agreed to carry out the project in a slightly reduced version compared to what was officially suggested by the organizers of *FCHgo!*, in particular by providing three presentations by me – of two hours each – on a weekly basis, alternated with two activities carried out by the teachers themselves between one presentation and another.

During my presentations, teachers (both Italian and German speaking) provided constant presence and valid support, favouring the participation and the attention of the children. In general, they appreciated the project very much, though did not always fully complement the project with the activities between presentations. Both the reduction of the number of my presentations and the quantity and quality of the complementary activities were justified on the basis of an already busy schedule of activities for the classes.

Kids exhibited always an enthusiastic participation, although in some occasions started to show signs of fatigue after about an hour and a half into the presentation. They posed many questions and concerning a very large spectrum (from television to stars) and have been equally responsive in answering questions, writing, reading and taking part to the dramatization.

The most appreciated moments were the explication of the various forces of nature and their interactions – especially when it came to perform little, simple and qualitative experiments – and the final dramatization. That was the part which had the greater success with teachers as well. Analysis of toys also had found a good interest, both during my presentation and during the teacher-led activities. The working of the hydrogen car received enthusiastic comments, but I had the impression that the pupils were more impressed by the general discourse on energy and its processes than by this particular application to the hydrogen car.

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3.3.3 Lower Secondary School Class 3 A and 3 C "FERMI"

1st meeting and 2nd meeting are very similar to the primary school ones (see above).

3rd meeting

Activities:

Draft some process diagrams (see *Introduction to FCH technology*)

Planning and writing of the storyboard for role play of one of the toys, preferably the Hydrogen car (ref. *Role Play Guide*)

First rehearsals of the role play

Remarks:

It took a long time to introduce the energy carriers and the exchangers, the carrier types and to make the example of the process diagram of the perpetuum mobile. For the next time pupils will try to make diagrams of the toys.

In the last minutes agreement about the rules for the play have been shared. (students -> carriers, locations -> exchangers). The students will do and record their play during the week, for next meeting.

4th meeting

Activities:

Comparing *Stories of the Dynamics of a Toy* (Rechargeable flashlight and Fuel cell car) (Ref: *Teacher's Toy Guide*)

Pointing out the analogies between the Rechargeable flashlight and the Fuel cell car (ref. *Teacher's Toy Guide*)

ADDITIONAL activity: discussion of the three advantages of hydrogen (renewable source, non-polluting, no need for combustion)

Remarks:

The pupils represented the plays of the Hydrogen car and of the Perpetuum mobile. Especially the groups with the more thoughtful kids did a great job (both in terms of language and gestures).

Individual students told what they interpreted and gave very detailed answers, an indication that there was thought behind it.

Made analogy between Fuel Cell with the two ampoules and a rechargeable battery, with due differences, advantages and disadvantages.

These themes were interesting and, especially the third, new. Some difficulty in understanding.

The school coordinator (dr. Mauro Sparapani) has left some note after the interventions.

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The activities and the didactic path are in general positive and suitable.

Concerning the disciplinary contents, some basic disciplinary knowledge have not yet been addressed in a class III of lower secondary school. All of this should be included in a didactic path that during the three years of schooling addresses in a progressive and experimental way themes such as force, energy, sources of energy, description of motion and work. This aspect would deserve a reflection on the science curriculum of secondary school.

Concerning methodological aspects, there are no particular problems. The methodology adopted is engaging for most pupils. Some of them find some difficulties in staging role playing. It would be appropriate to give them design and organization tasks (costumes, effects, filming, etc. ....).

3.3.4 Secondary School Class 4 A and 4 C "TORRICELLI"

1st meeting

Activities:

Viewing of the Perpetuum Mobile video

Discussion of the video in terms of energy carriers and texchangers/couplers

Construction of the perpetuum mobile process diagram with the help of the teacher

At the meeting was present the Polish partner, prof. G. Karwasz, who gave the lecture important contributions.

Remarks:

The lecture began with an introduction of the underlying concepts of the project (H_2 and non-hydrocarbons, Fuel Cell and non-combustion, energy and storage).

After the Perpetuum Mobile video, students are well aware of the impossibility of a cyclic insulated machine due to the production of heat and consequent loss of energy.

The construction of the process diagram of the Perpetuum Mobile was interesting and at the reach of the students.

Before next meeting, the students will do a laboratory activity with fuel cells.

2nd meeting

Activities:

Analysis of the hydrogen car with carriers and energy exchangers/couplers

Discussion of the hydrogen machine (see ppt with photos and smiles)

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Various carriers (conserved and non-conserved) and energy exchangers/couplers (with storage and not)

Construction of the process diagram of the hydrogen machine

Remarks:

Students had not had the time to go in the lab so the fuel cell was presented in the lecture.

The process diagram of the fuel cell, also as electrolyzer, has been produced in groups.

The students were very interested and did the task easily.

A discussion on the themes posed in the technical document “Introduction to Fuel Cells and Hydrogen Technology” has been done, due to the interest and the questions posed by the students.

At the end of the lecture the video “Hydrogen fuel cell: Its principle of operation, construction details, implementations and open problems” has been projected.

3rd meeting

NOT DONE DUE TO COVID RESTRICTIONS.

The school coordinator (dr. Diego Gottardi) has handed over a report after the interventions. Some relevant paragraphs are reported below.

The project was based on the analysis of experimental activities with devices that transform one type of energy into another and the analysis of transformation processes. In particular, the application of fuel cells to generate electricity compared with other types of voltage sources. Theoretical training on fuel cells and a series of experiments to be conducted in the laboratory from a qualitative and quantitative point of view were planned.

The activity has been introduced as an integral part of the physics curricula, which is the discipline most involved. This project has met with considerable interest among students also thanks to the fact that the municipality of Bolzano has included in its city bus fleet a number of hydrogen powered vehicles. Moreover, the Autonomous Province of Bolzano has a hydrogen production plant, intended for automotive use, with an environmentally sustainable cycle thanks to the exclusive use of electricity from hydroelectric power plants. T

The activity of the classes has been organized on four meetings with Prof. Corni who introduced the problem and, on a part, inserted in the disciplinary programs, entrusted to the class teacher for the deepening. Videos were analyzed in which the energy exchange and the role of energy carriers and exchangers were schematized and visualized. Then it was applied this "model" to the processes that occur in the fuel cell. The classes had already covered the operation of batteries (Volta and Daniell) in chemistry and physics, and then the operation of fuel cells was explained with emphasis on the role of proton exchange membranes (PEM). There was also a discussion on some objects present in our laboratory, an electric flashlight that works on the basis of magnetic induction or the dynamo used on bicycles, to identify the origin of energy and possible transfers that make it usable for lighting (in a

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fourth year it is however difficult to go into details: induction is part of the program of the fifth year). At this point the students were asked to make a presentation in which they could identify the roles of the various "particles" that with their flows and energy exchanges make possible the creation of a voltage able to power the electric motor.

The activities have contributed, often creating discussions among students, to make students aware of the roles of energy sources, energy vectors, losses and efficiency of the processes involved in comparison with those of endothermic engines against the same capacity to perform work. It was also possible to identify the final products of the process that have as "waste" heat and water vapor with obvious advantages over hydrocarbon engines, plus there is the advantage of renewability.

In summary, the experience was very positive because, in addition to the specific disciplinary content directly related to the theoretical and experimental activities conducted in class, it brought the students into contact with a scientific experiment/aspect that has significant consequences in everyday transport technology: all have traveled on buses moved by these devices that can have zero environmental impact. Awareness with respect to these application aspects is fundamental for the development of a scientific culture/consciousness in citizens. For high school classes, a less narrative and more technical approach would be desirable.

3.4 Elementary schools (Agado – Steinbeis 2i, Germany)

No extra activities in schools neither analysis was performed in the additional period. Here we report main points from the activities performed by June 2020.

The third party in German consortium, Agado, who supports us with the EPDM delivery, has implemented the classroom activities in five German schools during January and February 2020. The general outcome from these lessons is to be judged “middle”. We give an example from elementary school in Haag-Wolkar, 4th class, teacher Ulrike Krämer. In majority of answers the level of satisfaction was between 1 (the lowest) and 3. The same typology was reported from other 3 schools.

School	Date and Time	Number of pupils and class levels	Contents/Materials
Grundschule Haag-Wolkar (elementary school)	15 January 2020 11:15 – 12:45	4th class 22 pupils	Models/Toys
Werner-Egk-Grundschule Augsburg (elementary school)	29 January 2020 8:00 – max. 12:15	4th class, inlcusion school, 23 children	Models/Toys
Montessorischule Olympiapark (elementary school)	13 January 2020 8.30 - 10:30 And 11.15 - 12.45	3th and 4th class 14 pupils	Playing cards and models/Toys
Alexander von Humboldt Realschule Bayreuth (middle school)	05 February 2020	1 STEM activity group, approx. 20 pupils	Models/Toys

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Freie Aton Schule München (elementary and middle school)	January/February 2020	5th class 14 children	According to plan of UNIMORE for primary school pupils, age 8-13

Sandrina Felder

In my opinion, the learning process in general is too ambitious for the expected age group. The materials can only be used in parts in this way in the classroom or require their own additions. Approaching the topic through the story and making it experienceable through the role play is well accepted. The film and the other materials are sometimes simply too far beyond the children's comprehension, which is why they cannot be used as support material. Unless you live with the fact that only the fitter children come along. Therefore, a lot of time and work has to be invested by the teacher to develop material that can be used for support. With the materials available the students have problems to understand the content in its full dimension. That is a shame!

The technical content is exciting, highly up-to-date and could be explained to the target group in a simpler way or the target group could explore it in basic principles. For this purpose, information material would be helpful, which does not have to be broken down first. This requires additional time, which a teacher whose main focus are non-scientific subjects can hardly afford.

The following types of materials would be desirable:

1. What is energy? (The story works well)
2. What are energy carriers and converters? (Film helpful. The card game is my opinion too complex for the target group. Memory, Domino or simple question and answer cards, that are suitable for different games would be more helpful)
3. Energy types
4. Information on atoms, molecules and the operating principle of fuel cells (Only through the exploration of the models, the target group cannot access them).
5. Additional material for looking inside the models (flashlights, motor,..). Sometimes it is difficult to recognize the individual parts for drawing the sequences. Also, more detailed descriptions of the individual parts, e.g., for the flashlight, are needed.

The methodological content is varied and involves the children to a high extent. However, the material forces the teacher to be in the center of the learning process and to guide it to a large extent. Here a shift to the pupils themselves would be helpful and would promote personal responsibility and independent learning. Material with simple steps and possibilities for self-checking would make this possible.

Other comments or thoughts?

In general, I think that the topic: fuel cell and hydrogen is a bit missing, considering that this is the focus of the project. I think that without the background (before exploring the models or mediated/observed afterwards) an important part of the importance of this technology for the future is lost. I would like to see more target group adapted material.

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Ulrike Krämer

The pupils were very interested and enthusiastic about the topic. Especially the apple story, the movie Perpetuum Mobile, the models and the energy cards contributed to a better understanding of this very complex subject.

The pupils had difficulties to present the role play and to coordinate themselves accordingly. Since we had previously dealt with the topic of water and electricity (renewable energies), the pupils found an approach to the topic. However, the material was far from sufficient. First of all, the topic photosynthesis was taken up to introduce the pupils to the chemical terms (game). The term "atom" or "molecule" as well as the chemical formulas for water, hydrogen, oxygen and carbon dioxide and carbon monoxide had to be introduced. There were correspondingly self-created worksheets, blackboards and booklet entries. In addition, the pupils received information about the chemical procedures and processes in hydrogen electrolysis in the form of easy-to-understand films (Internet- Youtube) and worksheets.

The technical content is difficult to understand and, in my opinion, rather suitable for subject teachers of secondary schools or for primary and secondary school teachers with a corresponding study of chemistry, at least in didactics. For pupils from primary school the subject is only understandable in a very simplified form from the 4th grade on. The construction of a fuel cell car (model) was made possible thanks to the visit of a FCHgo employee. Hardly any primary school would have such a model, not even a twist torch.

Additional material had to be produced and easier methods suitable for primary school pupils had to be used.

In general, I think it is important to introduce the topic "renewable energies" in primary school and to use appropriate media and materials. The hydrogen car model was especially successful. In the classroom the topics were additionally introduced: Thick air, trees - our climate protection, 5 to 12, cars for climate protection, the sea - a blue wonder, all garbage - plastic in the sea from magazines: Staffete and animal lover.

Comparing the preliminary didactical outcome from Switzerland, Italy and Germany, the best results were obtained when additional material has been given to pupils/ teachers: potato battery as an example of electrochemical reaction (without saying it), dynamo torch as an example of energy conservation (but it must be clarified more specifically), printed “spirits” as examples of energy carriers. We note additionally that also in Poland some teachers for their initiative introduced the subject of garbage and more general – environmental protection.

The general impression of teachers was good, and they appreciated the technical contents. Probably a more direct relation to hydrogen questions should be developed in the final version of the didactical material and activities.

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3.5 Higher secondary school (DTU, Denmark)

Comments by prof. Anke Hagen, Dr rer nat. Dr techn., Department of Energy Storage and Conversion, Technical University of Denmark

Due to COVID-19 limitations lessons planned in Denmark were postponed several times. As writes prof. Anke Hagen from DTU "We finally succeeded to carry out some teaching in September, just ca. 2 weeks before the COVID-19 measures were again more tightened. That was lucky. Unfortunately, with all the precautions for giving the lectures, both before and during, I completely forgot to take pictures from the events."

DTU has carried out teaching under the main topic: How do we solve energy challenges of the future? How can fuel cells and electrolysis contribute?

The teaching was part of the National Arrangement "Videnskaben på Besøg" (Science is Visiting) in September 2020. The teaching was given in two schools to ca. 70 school kids from 7th to 9th grade.

The lectures were tailored according to the outcome of workshop questions with teachers. Main elements were:

1. Presenting and discussing the overall context of increasing shares of fluctuating renewable energy sources for electricity production, which require efficient technologies for storage and conversion, as energy cannot be created or disappear. Fuel cells and electrolysis are proposed solutions
2. Explanation of how fuel cells and electrolysis work, including showing an experiment.
3. Perspectivation of where fuel cells and electrolysis technologies are today.

In line with Danish teaching traditions, group/partner discussions and questions/answers were included for activating the students.

Examples for presenting the bigger picture are given as measured electricity input from renewable sources over a period of ca. one week in selected seasons vs. the actual consumption pattern (see Fig. 13). These actual values allow for concrete – in the Danish picture – discussion of the challenges from using more and more fluctuating renewable energy sources. Particularly wind energy is a source, which each student can relate to in Denmark and were discussed.

The working principle of fuel cells was demonstrated with an experiment (see video), shown schematically, including the involved main reaction. The focus was on showing that the only reaction

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product when using hydrogen is steam and heat. The knowledge state of the students was included and relations to topics from ordinary teaching were drawn.

In the final part of the lecture, the status of the technologies was shown and illustrated with movies, all of which involve fuel cells in their plots (see Fig. 14). The aim was to show that fuel cells (and electrolysis) are not merely exciting ideas of some researchers, but also have made entrance into the market. For each of the “fuel cell applications” in the movies, a real counterpart is shown:

- Terminator: application of fuel cells in the mobile sector: fuel cell vehicles and cars with fuel cells as range extender
- Star ship in Star Wars: fuel cells in the Apollo mission
- Hotel in 007: application of fuel cells in the stationary sector, powering supermarkets, office buildings, etc.

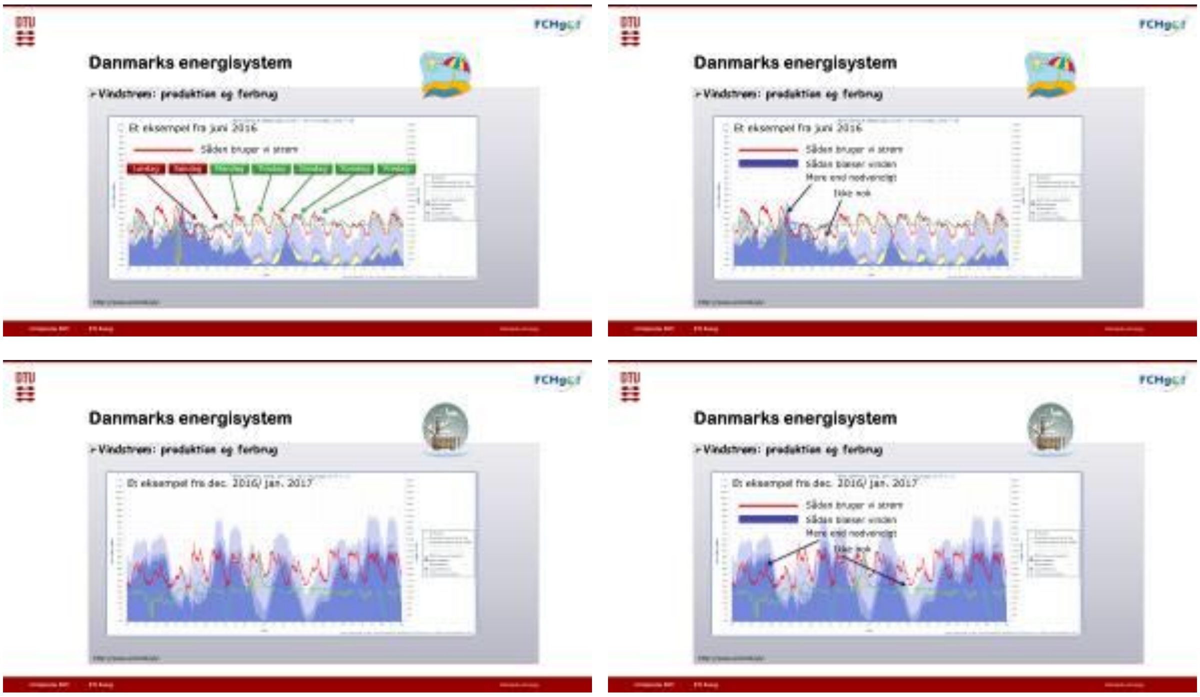

Fig. 17. Measured electricity production from wind (solar) over periods in summer and winter 2016 vs. the consumption pattern.

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Fig. 18. Movies, where fuel cells are mentioned to power certain devices and their real counterparts

Finally, the FCHgo project was mentioned together with the award (see Fig. 19).

Fig. 19. Advertising FCHgo and the Award.

3.6 Elementary and secondary schools (UMK, Poland)

3.6.1. Elementary schools (Kujawy region)

First series of lessons was done in the winter semester 2019/2020 (till the mid-term holiday break that in different regions in Poland is January-February). As reported in the deliverable D.3.3, the state of teaching at date 12 January 2020 was that 1/3 of lessons (2 hours with experts + 2 hours with teachers) has been done in all schools listed above. In Gdynia, Gniezno, Dąbrowa Biskupia and Słupsk, where the preliminary tests have been performed, 2/3 of teaching has been accomplished. The second part of January/first part of February are school holidays in different regions, so lessons were suspended, and were expected to resume in the second part of February 2020.

In total, in Poland 894 pupils were present at the first series of lessons (presence list collected), a number already comparable to the Project target (900 pupils). Nevertheless, the training was longer than predicted, even if 6 experts were employed simultaneously in the itinerary lessons.

The second run of lessons in Poland, with the full implementation of EPDM scenarios, as available and translated in February 2020 was planned for the summer semester 2019/2020. Practically, we

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managed only the initial series of meetings with schools on February 19th at UMK premises:

The third run was planned for the period September-December 2020. Unfortunately, even if the general lock-down at UMK started only with the end of October, single schools (where COVID appeared) closed already at the beginning of October, vanishing the plan for complete scenarios of 6 lessons.

Fig. 20. FCHGo lesson (G. Karwasz) in elementary school in Markowice (Kujawy province), 21st October 2020. (a) 2nd grade: children do not understand the principles of conversion of energy but enjoy much when wheels of a toys car with a PV panel start to turn. They do not know chemical elements, but some of them remember the formula "H_2O", so one can show two cylinders – one with a double width – to collect the two gases when H_2O molecule is split by the current from PV cell. These notions, scientifically correct even if expressed with simple words, can be taught starting from early elementary school. (b) Due to the COVID-19 restrictions no free experimentations were allowed.

Fig. 21. (a) Younger children (2nd grade in Markowice) were really unhappy not being able to touch experiments. (b) In the same school, children from 6th grade (11 yrs old) were pretty much interested in the subject of physics (now in Poland physics starts in 7th grade), energy and hydrogen, but without such enthusiasm, like it was in the 2nd grade. Due to COVID-19 no interactions were allowed.

The didactical conclusion from comparison between younger (2nd grade) and older (6th grade) pupils strongly supports the idea of narrative teaching in the subject of energy and hydrogen applied in young age. Pupils need not know chemistry or notions of physics but they enjoy spontaneously the conversion of light into electricity, the filling of the toy-car tank with hydrogen and oxygen and completely silent run of the "water-driven" car.

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3.6.2 Report on lessons in primary schools in Kujawy region (A. Karbowski)

Andrzej Karbowski is a researcher at Didactics of Physics Division, UMK. He also collaborates with different elementary schools.

The fourth phase of implementation of FCHgo teaching in schools has been done during the winter semester 2020/2021 and aimed in adopting the narrative scenarios on energy developed at ZHAW, UNIMORE and UNIBZ universities. The most difficult task in this phase was to integrate the scenarios with the new (from 2018) scholastic system in Poland, when the short (6 years) elementary and middle (3 years) schools were substituted by a unique, 8-years ("primary") school. An abrupt change of the system found the former elementary schools completely unprepared, as there was no physics as a separate subject, but only "nature". In the new school there is no "nature" so the interdisciplinary scenarios that we prepared to teach problem of environment, energy and emerging technologies needed to be modified.

The second difficulty with this phase was that from September schools were officially opened, but in those where some COVID-19 infections were detected got closed immediately. This caused the impossibility to perform the planned lesson in classes and we needed to prepare on-line lessons. We choose two primary schools in Kujawy region with which we had previous contacts – in Kowalewo already FCHgo lessons were held (7th grade) and the school from Pruszcz contacted us recently (they usually participated in lesson for schools at UMK).

Three slots of two-hour lessons were held on November 9, 16 and 23, 2020, in 6th grade at the primary school in Pruszcz, while on 10, 17 and 24 November there were 3 lessons in the 6th grade at the primary school in Kowalewo Pomorskie. As said above, due to an unexpectedly rapid development of the COVID-19 pandemics in Poland, lessons were carried out remotely on the Microsoft Teams platform, which students use every day for all their lessons at school. The lessons were carried out without major technical problems as the students knew Teams and were able to use it very well and freely.

Due to the above-described specific moment of the Polish educational system (and low social sensibility to the global warming) we inverted slightly the scenarios elaborated at ZHAW and UNIMORE: we started from the information on the climate changes, then on alternative energies and hydrogen technologies and we finished with the general discussion of the term "energy".

In all lessons, students were focused on the topics and issues discussed, they were active and showed pretty good general knowledge. They were happy to answer the teacher's questions, they also asked interesting questions themselves and took an active part in discussions.

In the first slot of lessons the climate change was discussed. We used the material prepared for secondary schools (PowerPoint presentation from UMK FCHgo repository on local web pages http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/FCHgo_1_Klimat.ppt) but some details were omitted, and we concentrated the attention of pupils on the most important (and appealing) pictures.

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Fig. 21. The screen of the Microsoft Team program during the lesson at the primary school in Pruszcz.

The students learned whether the climate is really changing and what determines it, e.g., astronomical cycles, learned about the role of the Earth's atmosphere and learned about the main greenhouse gases: H_2O and CO_2. The students were surprised by the fact that thanks to the presence of water vapor in the Earth's atmosphere, the average temperature on Earth is not -18 °C, but +15 °C, i.e., the difference is as much as 33 °C. They also learned the scientific evidence that there is a correlation between the amount of CO_2 in the Earth's atmosphere and the average temperature on Earth. They liked the graph showing the historical records of CO_2 in the Earth's atmosphere from 900 to 2000.

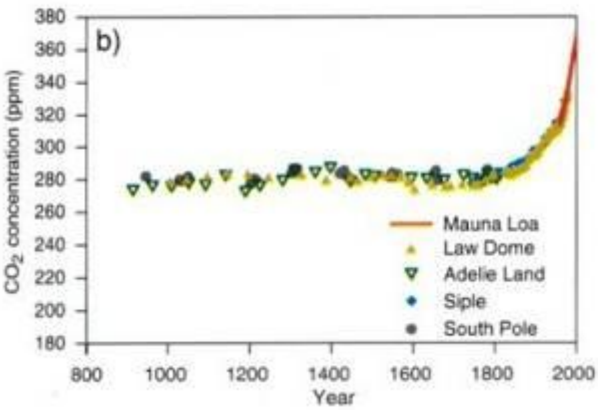

Fig. 22. Historical changes in CO_2 content in the Earth's atmosphere (Source: Scripps Institution of Oceanography).

The students combined the facts from the history lesson and guessed what the influence of steam engines and the industrial revolution on the CO_2 content in the Earth's atmosphere was. They noticed that since 1850 there has been an increase in CO_2 content from 280 ppm (parts per million) to 415 ppm and calculated with the help of the teacher who taught the lessons that this was an increase of almost 50 %. On the basis of scientific data, they found out that the global temperature on Earth undoubtedly increased from 1850 to 1996 by about + 0.4 - 0.6 °C.

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Students actively participated in the discussion on the sources of CO_2 in the atmosphere and were able to identify the sources of emissions of this greenhouse gas. They listed here: old-type coal-fired furnaces for heating houses, coal-fired power plants, large industrial furnaces, e.g., in steel mills and heat and power plants, fumes emitted by trucks, buses and passenger cars, passenger planes with jet engines, ships, forest fires in various parts of the world, meadow fires and fires, etc. They also eagerly discussed the melting glaciers in the Arctic. They knew these facts from television, radio, books, magazines and the Internet. However, they were unaware of the scale and speed of this phenomenon. They understood very well that the cause of climate change is the burning of natural resources based on carbon.

In the second slot of lessons, alternative energy sources were discussed with pupils. It was noted that these are renewable energy sources such as: wind energy, water energy, solar energy - solar panels, energy obtained from biomass combustion, geothermal energy etc. The historical aspect of humanity's transition to various energy carriers turned out to be very interesting: wood, coal, natural gas, petroleum, solar energy, nuclear energy or thermonuclear energy. They had their maximum consumption years, e.g., for coal it is the beginning of the 20th century, and then the use of this energy carrier decreased.

The students were happy that there was an optimistic scenario to stop CO_2 emissions. This gives them hope that they will live in a clean environment and that their quality of life will not deteriorate. They understood the fact that alternative energy sources do not emit CO_2 into the atmosphere and are friendly to the environment in which we live. They mentioned various places in their vicinity where windmills were built, they were able to justify that due to the presence of strong winds at sea, the conditions for the construction of large wind farms are the most favorable. Information on various types of photovoltaic panels turned out to be very interesting for them.

The children were able to justify why it is worth installing solar panels on various buildings and why there are more and more of them, due to the economic profitability of such energy sources. They were a bit surprised that the efficiency of the solar panels is so low, 6% for modules made of amorphous silicon, and 10% for modules consisting of microspheric silicon.

They understood that the demand for electricity in Poland will continue to grow and that it is necessary to build a nuclear power plant in our country. They listened with great interest to the information about the construction of a fusion power plant in Cadarache in France. They would like it to be built and put into operation as soon as possible, without unnecessary delays, for the benefit of all EU countries. They were very impressed with the size and complexity of the ITER tokamak.

Almost all renewable energy sources depend on the weather, wind and sunlight. The problem with generating electricity occurs when there is no wind and the sun is not shining. In this lesson, students also learned that hydrogen is the fuel of the future. It can be produced in photovoltaic cells and stored in large tanks or cylinders under high pressure. They loved the water-driven car. They saw how hydrogen and oxygen gas are produced in two tanks and how electricity is produced in a fuel cell. The car drove around, flashing lights, and making noises. It was powered by hydrogen and oxygen and did not emit poisonous exhaust gases. Many of them would like to have such cars. The students also saw experiments with: an electricity generating windmill, a dynamo flashlight, a car with a solar cell, a lunar vehicle with a solar cell, a windmill with a solar cell.

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In the third series of two lessons, the students got acquainted with the concept of energy and learned about the transformation of energy. They liked the definition of energy, and it was very easy for them to understand that it was the body's ability to do work. They read from the label on the box with fruit juice what ingredients are in it and what is the energy value of the product in kcal. They got acquainted with various energy carriers and their transformations. They also learned about the energy transformation in a fuel cell. The scheme developed in the FCHgo project (see Fig. 23) turned out to be very understandable to them.

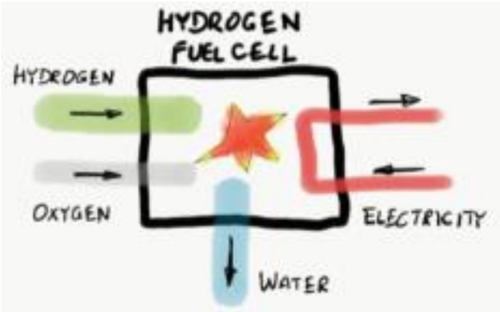

Fig. 23. Diagram showing the energy transformation in a fuel cell (Source: H. Fuchs, FCHgo material)

The students really liked the “Apple story” and the energy transformations that occur here. They also watched a movie about Perpetuum mobile with great curiosity and wondered whether such a device could be built. They pointed out that energy is transformed into energy losses and that this part of the energy is converted into thermal energy, which dissipates into the environment.

They listened with great interest to information about real cars with fuel cells and about other vehicles with such cells: buses, trains, ships, planes, etc. During the lesson, a series of very interesting experiments was made with the following teaching aids: a dynamo flashlight (manual power generator), a bicycle wheel with dynamo, drinking bird, Stirling engine with burner, hydrogen was produced.

The lessons planned and carried out in this way turned out to be very interesting for the pupils, engaging in discussion and active learning, which was combined with fun and a lot of physical experience. The concepts presented were not too difficult for the students, and the problem of hydrogen as the fuel of the future was a bit surprising for them, but they understood that it is necessary to limit the combustion of fossil fuels and reduce CO_2 emissions to the atmosphere.

The FCHgo project turned out to be very useful for them and the students became very involved during the lessons at their school. They are currently working on competition works that will be submitted to the announced competition in the FCHgo project.

3.6.3 Report on lessons in primary and secondary schools in Kujawy region (K. Fedus)

Prof. Kamil Fedus is an associated professor in Didactics of Physics Division. Apart didactics his subjects are Solid State Physics and Atomic Physics.

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Kamil Fedus has carried out FCHgo teaching activities in five different schools in Poland located at the province of Pomeranian and Kujawa-Pomeranian Voivodeships:

- Szkoła Podstawowa w Mikołajkach Pomorskich (elementary school)
- Szkoła Podstawowa w Prabutach (elementary school)
- Zespół Szkół Ogólnokształcących nr 1 w Kwidzynie (high school)
- Zespół Szkół Ogólnokształcących nr 2 w Kwidzynie (high school)
- Zespół Szkół Technicznych w Grudziądzu (high school)

The different levels of schools make very useful the comparison how the FCHgo methodology may be applied at all educational stages. At two elementary schools the lectures were delivered in the form of workshops. The targeted children were 13 – 14 years old. The first part of teaching was organized in stationary mode and children learnt about electricity and energy sources including traditional batteries, solar cells, different types of power plants: wind, water, nuclear energy and coal-fired power stations. Didactic models and simple tools were used to illustrate the principles of operation of the above-mentioned sources of electricity. As the classes were interactive, the children had the opportunity to test all devices themselves. In particular, the children had the opportunity to build their own simple batteries (the voltaic piles). Fuel cells (hydrogen powered) have been introduced as an alternative source of energy to those described earlier. In particular the fuel cells combined with renewable energy sources were described as eco-friendly energy supplying systems that will be common in every household in the near future. All of children participating in the workshops heard for the first time in their life about fuel cells and their potential applications. This concept was completely new for them.

Fig. 24. FCHgo workshops on electricity sources, renewable energy sources and hydrogen fuel cells at Elementary School in Mikołajki Pomorskie (polish name: Szkoła Podstawowa w Mikołajkach Pomorskich). The report on this activity (in Polish) can be also found on the school website: http://www.zsmikolajkipomorskie.szkolna.net/n,miedzynarodowy-projekt-fchgo-discover-the-energy-of-hydrogen. Due to the COVID-19 restrictions some lectures were also organized on-line.

Due to the school closures caused by Coronavirus (COVID-19) and related restrictions imposed by Polish Government, the second part of teaching was realized in the form of on-line courses. In this part the children learnt about different energy forms (motion, chemical energy, heat, light, electricity). Many illustrative examples (in a form of movies or high-quality simulations) were used to demonstrate the energy conversion.

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In particular the "Apple story" available in the FCHgo toolkit, see for example the repository: (https://drive.google.com/file/d/1T4lTs1_LKgDytouREcJvVORbB8tB-jt-/view) was analyzed with children in order to show (in a narrative way) an analogy between principles of operation of living organisms and complex devices such as fuel or solar cells (in the terms of energy conversion). Moreover, the movie entitled "Perpetuum Mobile" from the FCHgo toolkit, see the repository (https://drive.google.com/file/d/1Yu0HpYxa-YkJdr1MaFMk0I7UdndhuEzI/view) was used to demonstrate the importance of heat in energy conversion systems (i.e. the waste of energy caused by its escape from the system in the form of heat). To illustrate the hydrogen fuel cell in real action, the movie demonstrating the toy car powered by water was used, see local UMK repository (http://dydaktyka.fizyka.umk.pl/fchgo/filmy/Fizyka_dosw_70.mp4). The car was combined with solar cell in order to produce hydrogen for fuel cell through the process of electrolysis. Based on the acquired knowledge the children tried ("brainstorm") to describe the principles of car operation using the language of energy conversion and identify particular elements of the device were the specific transformation takes place. In particular the production of little heat was underlined (i. e. little waste of energy) in systems powered by fuel cell when compared to traditional heat engines used in majority of cars (engine gets very hot in running car).

Fig. 25. FCHgo lecture on the global warming, the climate changes and the advantage of fuel cells and renewable energy sources over traditional ("dirty") carbon-based sources carried out at the I High School in Kwidzyn (polish name: Zespół Szkół Ogólnokształcących nr 1 w Kwidzynie). The report on this activity (in Polish) can be also found on the school website: http://zsokwidzyn.pl/index.php/2020/05/15/projekt-fchgo-odkryj-energie-wodoru/ .

At the high school level, the teaching about hydrogen fuel cells was realized in the form of academic lectures combined with simple demonstrations, simulations and movies. The targeted youths were 16 – 17 years old. The fuel cells were introduced in the context of global warming and climate changes. The lectures included many elements described in the teacher guide on FCHgo lessons and available in the FCHgo toolkit (https://fchgo.eu/toolkit-development/). In addition, surplus materials elaborated by FCHgo team from Nicolaus Copernicus University in Toruń (Poland) were used (http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/857).

The beginning of the lecture was devoted to the main problems related with the use of fossil fuels. In particular the sustainability as well as the emission of CO_2 (global warming) and toxic gases were underlined as the major factors that will shift the world's energy consumption away from fossil fuels. The problem of carbon-based fuels is especially important in Poland where more than 75% of energy is still produced from coal. Moreover, the quality of air in Poland is one among the worst in Europe.

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Fig. 26. FCHgo lecture on the global warming, the climate changes and the advantage of fuel cells and renewable energy sources over traditional ("dirty") carbon-based sources carried out at the II High School in Kwidzyn (polish name: Zespół Szkół Ogólnokształcących nr 2 w Kwidzynie).

Fig. 27. FCHgo lecture on the global warming, the climate changes and the advantage of fuel cells and renewable energy sources over traditional ("dirty") carbon-based sources carried out at the Technical High School in Grudziądz (polish name: Zespół Szkół Technicznych w Grudziądzu). The report on this activity (in Polish) can be also found on the school website: https://planetarium.grudziadz.pl/index.php/component/content/article/8-aktualnosci/160-zajecia-dla-dzieci

The hydrogen fuel cells were introduced together with renewable energy sources as the main elements in the energy diversification that are free from the disadvantages of fossil fuels. Numerous examples of current and potential future application of these alternative energy sources were described. The final part of the lecture was devoted to the principles of fuel cell operation. The focus was on showing that the only reaction product when using hydrogen as a fuel is water steam and some heat (in other words, it is the water going out from car's exhaust pipe instead of toxic gases). The subject triggered vivid reactions among students and interesting discussions during and after the lectures. Despite school closures caused by COVID-19, the students from some schools were engaged in additional activities including research projects developed by FCHgo team from UMK Toruń, see for example (in Polish) http://zsokwidzyn.pl/index.php/2020/05/15/projekt-fchgo-odkryj-energie-wodoru/ .

Overall, over 250 students from five Polish public schools participated in the FCHgo classes carried out by Kamil Fedus.

3.6.4. Elementary schools (Pomerania region)

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Didactical conclusions on implementation of FCHgo teaching scenarios in elementary school (8-12 yrs old) by dr Anna Kamińska

Dr Anna Kamińska, UMK and Pomeranian Academy in Słupsk researcher, in charge of coordinating FCHgo lessons in elementary and secondary schools in Pomerania region, co-author of experiments, supervisor of teachers.

The FCHgo scenario for children of lower classes of the primary school (that in Poland is now 7-15 yrs) starts from the "Apple story" which offers the introduction into the subject of food/ fuels and energy and the basic notions needed for pupils to make them understand the role of fuels in our live. Such a "fairy-tale" is a natural environment for children, and the level of narration on eating and natural processes is appropriate for the perception of children age 8-12 yrs.

My didactical observation is that some introducing discussion would be needed, in order to check what children already know. Questions like "what is needed for movement?" could be asked. My experience from lessons done is that children already intuitively answer "energy!". Then, I follow with statement that the energy is needed not only for the movement, but for the life in general.

Next suggested question could be "where does the man take from - all this energy needed to move, breath, and grow?" The answer: "from eating, i.e., food. And now we can verify it in reality – checking the information printed on packets of food (juices, cookies, sweets) that children keep in their schoolbags: what is the "energy contents" (in calories). Children can find autonomously this information and exchange observations with their friends. Food is the "energy carriers": labels on food testify it.

The next step in the FCHgo scenario is the Apple story. Children are able to draw autonomously: some invisible forces of nature (spirits) act and cause the grow and ripen, and these – in turn – supply us with energy: are our fuel. We complete the conclusions: these are components (water and gases) that combine into new substances (like sugar) thanks to a pretty visible "spirit" – sun light, bringing the energy. Water and gases are bricks, and the energy coming from sun organizes these bricks into a new, great (and tasty) construction.

Further, we can show some simple objects from the virtual collection „Physics and Toys" (http://dydaktyka.fizyka.umk.pl/zabawki1/index-en.html) that illustrate principles of energy conversion, like Crookes mill, converting the heat brought by light into the rotation of the "wind-mill" (http://dydaktyka.fizyka.umk.pl/zabawki1/files/termo/crooks-en.html); "love thermometer" converting the warmth of hands into the rise of the liquid

http://dydaktyka.fizyka.umk.pl/zabawki1/files/termo/termometr-en.html

or Stirling's engine http://dydaktyka.fizyka.umk.pl/zabawki1/files/termo/silnik-en.html

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Fig. 28. Simple experiments to enrich the discussion on energy transformations - heat into mechanical work: Crookes “wind-mill”; “love meter”; Stirling’s engine.

We note that in the whole FCHgo scenario children liked the most their own experimenting. Even without direct explanations from the teacher, they arrive to the conclusion that in “toys” like the hand-dynamo, the wind-mill or electrical cars supplied with photo-voltaic cells, one form of energy is converted into another form. “Ghosts” from the “Perpetuum mobile” film are a useful visualization.

During next meeting we show the electrical car fuelled with hydrogen cell. We explain that the fuel cell works as Volta’s pile – producing “the electricity”. Children construct a simple voltaic cell from apples or potatoes and a pair of different metals: this can be copper and aluminum, brass and iron, or, willing – gold and zinc. The teacher knows that it is important to choose two metals that differ in the position in Volta’s electro-chemical series. In Poland we use these concepts in children’s education (on the example of Italian teaching) already for some years (see the page “Sources of electricity”

In case that the hydrogen car is unavailable (or has at the moment of the lesson some technical problems like broken cables) we have constructed a virtual support for Polish teachers on the page http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/854. Short clips with photovoltaic cars and hydrogen fuel cells are shown there.

The own construction of “fruit” battery brings a lot of fun to children. We need not explain them details of electrochemistry - we can do this in the upper classes of Polish elementary school (see the didactical material on fchgo.eu). On the level of early elementary school, we must explain only that it is *chemical energy* that is transformed into the *energy of electricity*. With these expressions we do some simplification but the very idea of the conservation of energy, input and output potentials, entropy etc. (see the educational material by H. Fuchs) is preserved.

In order to fix better the idea that the voltaic cell is not at “zero cost” we can show old, corroded “finger” piles or after some minutes of working of “apple pile” we can show that the part of the apple that was in contact with the iron nail is “dirty” (and we can add that its taste is different, but we do not allow them to try it during the lesson) and also the nail changes its color.

The experiment with “potato” battery is very useful also didactically – showing that the (iron or aluminum) electrode is corroded, it is easy to explain that this kind of battery is not *reversible*: “you understand, that to make this battery work again we would need a new iron nail and also a new potato”. “This is why you need to by a new pile when the old one is *exhausted*.” “You understand that it is expensive. In your cell-phone and computers you have some *rechargeable* battery but also that is not forever and after some years it must be changed.”

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In this way, it is easy to explain the advantages of hydrogen fuel cells: ”You know understand that instead of digging iron ore and melting it in thousands of centigrade we simply take water, insert two electrodes and collect the two gases – one is called hydro-gen another oxy-gen [in different national languages we can use a similar word-play, depending on the word’s etymology]. We can collect these gases in the bottles and use whenever we need it. More: we may do it many times. During the day your father’s will circulate in the city, and during the night it will be plugged into the home electricity, in order to charge the *hydrogen* battery.”

Even my colleague teachers have some difficulties in understanding that two metals from a traditional Volta’ pile may be substituted by two gases. But all of them had the concept of Volta’s series in the secondary school, and know that the “normal electrochemical potential” is referred to a “hydrogen electrode”, that has a strange construction – a plate of platinum covered with “black platinum”, “Why not just platinum as an electrode?” So, we use thus teacher’s knowledge to add: “now you understand that exactly the same happens in the hydrogen fuel cell, and you understand also why the cell is expensive – it requires *colloidal* (i.e. nano-powder) platinum”.

This part of lesson can be summarized by showing again that any two different metals (like in aluminum pencil-sharpener) can produce “a voltage”, So does hydrogen and oxygen in the fuel cell.

The final lesson is summary and working with working model of a hydrogen-fuelled car (we chose a model from Horizon). The class should be divided into two groups – while one group works with different photo-voltaic toys (the choice depends on the availability, see FCHgo_2_Alternative_Exp.pdf document), the other group us busy with charging the hydrogen-oxygen tank – making annotations how the volume of two gases rises and how it depends on the light source). When the first group already exploited the range of possible experiments with photo-voltaic “toys” (the teacher must note the precise moment that children exhausted their constructive ideas and start an “idle” playing) – the roles change: the group that played with cells now gets the hydrogen car with filled (need not be full) tanks, connects properly the wires and sends (on the floor) the car to the second group. The “race” can be repeated several times. Unfortunately (but didactically fortunately) Horizon cheap models are far from being perfect, so the car soon stops. We can use this fact for a didactical comment: “Exactly the same happens with real hydrogen cars. Now you see that mode engineers and scientists are needed to make it work on hydrogen technologies.”

The main attention of the teacher during the experimentation should be to avoid the damage to the car (the lamp too close to the photo-voltaic cell, normal water instead of distilled water, broken wires, wheels blocked, and even spilling water on tables).

We explain also to children the advantages of the hydrogen fuel cell: no exhaust gases, no heat, no noise. If we use additionally Stirling’s engine (with the boiling water as the heat source) it is even more evident that the hydrogen fuel cell in the “water-driven car” is not warm. We explain that in a normal combustion engine (and also in Stirling’s engine”) majority of heat is lost “into the air”. In hydrogen car we used silent light, got hydrogen and oxygen in silent process, and again the electrical engine does not warm when the car circulates in the classroom. Obviously, these are some simplifications (see video lesson no. 4 by G. Karwasz) but potentially the efficiency of the hydrogen fuel cell could arrive to 80% as compared to 25% in a normal combustion process. (We hide somewhat low, 10-15% efficiency of the solar cells, but it can be always compensated by a greater surface covered by PV panels.)

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We leave some place to a free discussion for what one could use the FCH cells in the future, if they become popular and cheap.

We noted in different lessons (city and rural schools, small and big class groups, lower and higher ages) that children (in Poland) are much more sensible about problem of environment than adults. Further, with a proper, simple but illustrated by some experiment's narrations, we can address properly the attention of even small children. Making the discussion somewhat broader – about HFC, emission of greenhouse gases, burning coal and creating smog, extinction of traditional fuels – we can induce a correct attitude towards the environment (and economy) even in the youngest pupils of the primary school.

Pedagogically, autonomous experiments – both with simple objects like potato battery and with "water-drive" car trigger a lot of positive emotions among children. From checks done few months after lessons they remember "the lesson with that professor who gave us the funny bug jumping in sun".

Resuming, in my opinion the FCHgo project proved to be very successful. Further actions will be to extend the line of narration and experiments to other school, not only of Pomerania and Kujawy regions. Articles resuming both experimental and pedagogical aspects of "hydrogen lessons" will be published at national and international congresses in didactics.

3.6.5. Secondary schools (Pomerania region)

Didactical conclusions on implementation of FCHgo teaching in secondary school (T. Bury)

Mgr inż Tadeusz Bury is the teacher of physics, informatics and technics in two, different types of Polish Secondary Schools: Electrical Technicum in Gdańsk (formerly 4 yrs and now 5 years school) and General Lyceum in Gdynia (formerly 3 yrs now 4 yrs school). He is also the subject advisor in informatics for secondary schools in Gdynia Municipal Inspectorate.

In spite of essentials difference in programs, target groups (and attitude of students) FCHgo lessons and in particular experiments triggered vivid interest in both schools. This experience has matured over the period of three school years (2018/2019. 2019/2020, 2020/2021) but in quite distinct, to some extent alternative modes. These modes were as follows:

2018/2019 (March-April 2019), lessons for jointed classes (c.a. 60 pupils) with some preliminary Educational Material (experiments on alternative energies and hydrogen fuel cells from UMK) and direct lectures by prof. G. Karwasz and dr A. Kamińska (IX Lyceum Gdynia)

2019/ 2020 (September – December 2019) with FCHGo on-line lectures from UMK (prof. G. Karwasz) and set of experiments from Pomeranian Academy (dr Anna Kamińska) on alternative energies, photovoltaic cells and hydrogen

2019/ 2020 (February – March 2020, interrupted by lock-down) with EDPM translated into Polish

2020/2021 (September – October 2020, interrupted by lock-down) with full EPDM and set of experiments (from UMK, Pomeranian Academy and won resources of the teacher).

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Experiments done during the FCHgo workshops showed not only the model of the car with a hydrogen fuel cell, but recalled earlier notions of the green, i.e., environment friendly renewable energetics, related to the conversion of the energy of wind, light or chemical energy into the electricity.

At Technicum of Energetics, in spite of the technical character of the school, it was quite surprising that none of the students has met in the earlier educational step (i.e., in the lower secondary or in the extended primary school) any practical activities related, for ex. to Volta's pile. During FCHgo workshops they have the very first possibility to construct "with own hands" electrochemical piles or assemble a photovoltaic device supplying the current to a lamp or to an engine. This allowed to construct also the concepts of the energy transfer (instead of speaking of "energy production").

The lesson with the university expert was also the possibility for the teacher, who encouraged by the experiments with Sterling's engine which he had seen for the first time in a real experiment, imported via internet some simple (and cheap) experiments with photovoltaic cells and thermodynamic engines. Unfortunately, experiments with hydrogen fuel cells are rather expensive.

Different were impressions from lessons in Lyceum in Gdynia, where students already knew (from the elementary school) some aspects related to, say, Volta's piles. From my knowledge this type of practical experiments in elementary schools were done thanks to additional training of the teachers when (several years ago) a new subject called "nature" was introduced into secondary schools (and now has been cancelled): some teachers, for ex. of geography got an extra preparation in interdisciplinary subjects, and one of them included the electrochemistry. Those teachers were instructed during the training on the importance of practical experiments that could be performed autonomously by pupils in the classroom using, for ex. potatoes, apples, lemons and available pieces of different metals, like coins, aluminum foil from chocolate, or cans from drinks and electrical wires and observe how the chemical energy derived from these constructions changed into the electrical energy.

In the present moment in the Polish secondary schools there is no division into smaller groups (and some classes count up to 30 students) on physics or chemistry lessons so there is no possibility to participate in practical experiments. These experiments can be seen only during visits at university laboratories or science centers like Experiment in Gdynia or Hewelianum in Gdańsk, that is the stakeholder of FCHgo and will implement fully FCHgo experiments after the conclusion of the Project.

The possibility to perform independently experiments gave students not only knowledge in electricity, electrochemistry and hydrogen technologies but also showed them how to cope with difficulties and technical problems, how to perform multiply trials, how identify the reasons of the failure, how collaborate within own experimental groups and how use the experience of colleagues.

Similar impression got students from the seminar organized in March 2019 by UMK at IX Lyceum in Gdynia, where the most spectacular experiment with assembling the Volta's pile by 5 girls keeping their hands (via a bimetal joint) was even reported in the FCHgo Project newsletter. The narrative approach to this type of experiments ("what can we do when your cell phone fails during a party with friends?") was remembered by pupils of different age, coming from the whole Pomerania Province.

Students from IX Lyceum stressed after that Seminar that only now they managed to understand several separated aspects that they learned (or better – only heard) in the primary school. In spite of the time elapsed from the primary school, the practical (and funny) experiments and the narrative

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style, that included the history, some objects (like a beer can in a form of the Volta pile, an Italian banknote with his picture, a “volt”-meter etc.), physics and chemistry allowed them to see everything at once, and what is even more important – participate actively in this “science adventure”.

As the final outcome of FCHgo lessons I stress the complexity of the approach and the notions learned. Students understood that the additional greenhouse effect induced by human activity is a real scientific, technological and economic problem, that the traditional fuels are not unlimited and that new technologies, first of all in transportation, must be (urgently) introduced. As a summary – we have installed in the classroom a small station to charge cell phones, supplied by PV panel. This energy is “free”, as is not produced at the cost of burning coal somewhere in South of Poland (Silesia) and at the cost health of their friends there breathing benzopyrene. As the outcome of the FCHgo project we also installed with students a small station checking the quality of air outside the class window.

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4. General observations and comments

4.1 Comments by teachers

Dr Anna Kamińska, mgr Tadeusz Bury

Need for didactical material

Secondary schools in Poland of general profile (Lyceum, age 15-19) have in programs pretty much of physics and mathematics. Notions like energy, efficiency, thermodynamics are already well known. Usually, also experiments on electricity, Volta's piles, and in chemistry (like electrolysis) are already seen by students in earlier education.

On the other hand, teaching is little inter-disciplinary: water seems a different substance when discussed in physics and in chemistry. This is the reason we wrote a series of papers for Polish "Physics in School" and a paper for "Chemistry in School" is under preparation, see Fig. 29.

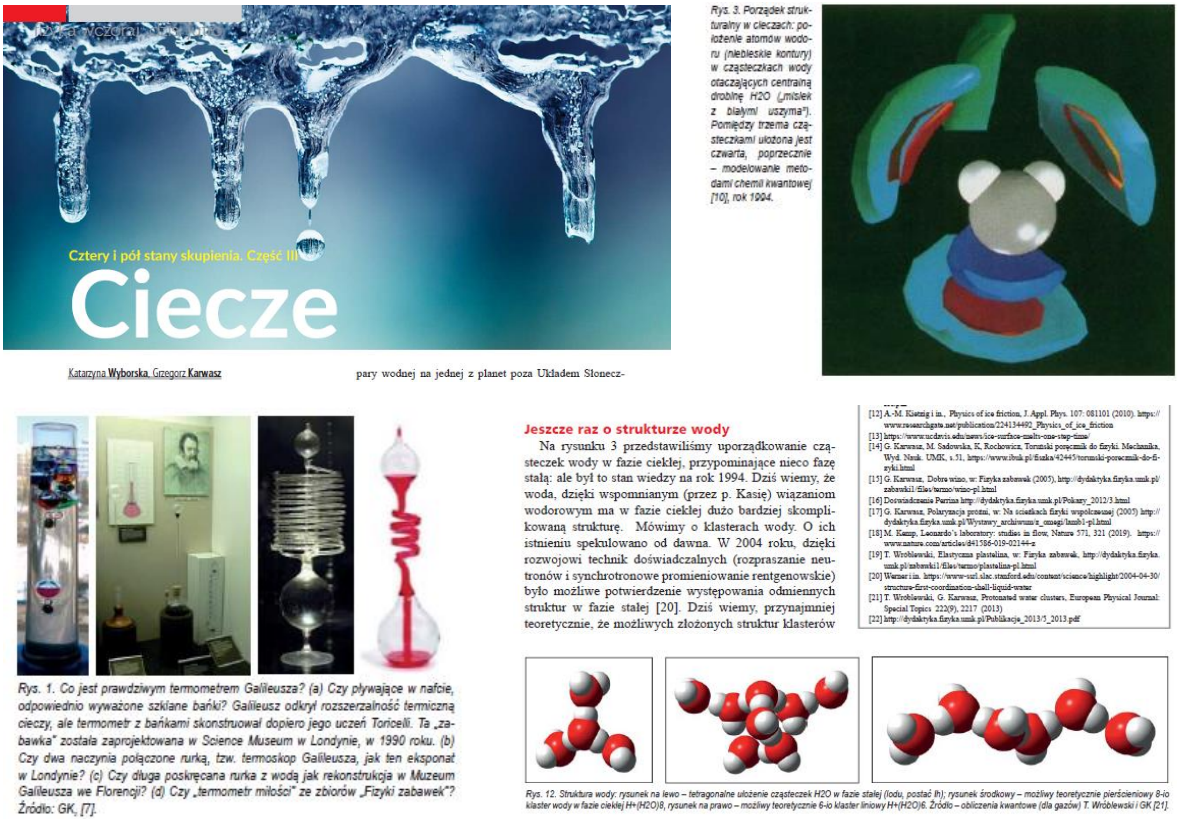

Fig. 29. Additional didactical material for teachers, to enrich their interdisciplinary attitudes: Liquids by K. Wyborska & G. Karwasz in "Physics in School" – title page (a); complex structure of water – one molecule surrounded by four others (b); thermal capacity, thermal expansion and evaporation (c); water clusters in gas and liquid phase (d).

Another weak point in Polish cv in secondary schools are aspects of the climate, energy and alternative energies: the reason, we can say, is "politics". Polish main energy "source" is still carbon (together with countries like India, Kazakhstan and China) and governments insist on continuation of these polices

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(prof. G. Karwasz participated, as a spectator, in 2018-2020 in three public meetings, organized by Polish Ministry of Energy, in which these polices were confirmed.) As compared to Denmark, Italy, Germany, alternative sources of energy (wind, photo-voltaic) are still few. Poland is one of the biggest producers of hydrogen in Europe, but it comes from natural gas (CH_4) and is energy-consuming. This hydrogen is used in chemical industry and is not enough clean to be used in FCH. Again, the change of thinking is needed.

Indications for lessons

FCHgo scenarios were implemented in schools of Pomerania Region (Gdańsk, Gdynia, Słupsk). We start the FCHgo lessons in secondary schools with the meeting with the academic expert; the subject is the climate changes. Surprisingly, even if this thematic is not treated adequately in the school, students presented quite high level of interest and, collectively, pretty high level of awareness. They are aware that recent changes in climate result from human interference into natural processes and are due to the industrial development. They also know, even if vaguely, which factors influence the climate and air pollution. They agree on the necessity for the reduction of CO_2.

The hydrogen fuel cells turned out to be completely a novelty to them. During lessons with university experts, we showed several advanced experiments, like the absorption of the IR radiation by surfaces with different albedo, thermo-vision TV camera, sensors of air quality. Additionally, we showed also simple “physical toys” – i.e., bugs, race cars, “wind-mills” supplied with photovoltaic and hydrogen fuel cells.

Fig. 30. Workshops with FCHgo scenarios „Climate changes” in IX LO Gdynia

Didactical outcomes

The didactical outcome was checked using simple questionnaires, with typical questions “Do you agree that…?” 81 students were tested in the three secondary schools (Gdynia, Gdańsk, Słupsk), by their teachers, after approximately one month after lessons.

10% of students in tested stated that the climate on Earth changes because this is the total energy emitted by Sun that undergoes variations. 65% agree that the most important greenhouse gas on Earth is CO_2. 62% remembered from the lesson that the level of CO_2 was approximately constant in the last one thousand years, till 1850 when it started to rise.

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When asked which arguments to stop burning coal in Poland are the most important – students in the first instance answer that it is the rise of the mean temperature on Earth (global greenhouse effect) – 71%, then that the unacceptable high level of benzopyrenes in air in winter 42%. They do not like the smoking chimneys of houses (20%) and high social costs of the extraction of coal (12%).

The second slot of two lessons within FCHgo was devoted to Volta's pile and hydrogen fuel cell. After a short PowerPoint presentation on Volta's discovery and showing different types of electrochemical batteries, we divided the class into groups of four persons. Each group received a set of materials to build Volta's battery: 5 gr (brass) and 10 g (nickel) coins, paper and brine (salty water). In addition – apples, small metal plates (copper and aluminum) and voltmeters. The aim was to construct autonomously a pile giving some voltage. We gave no precise indications as students already listened to the Power Point lesson (http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/FCHgo_3_Volta_pl.ppt). First trials were without effect but when finally, students measured some voltage they were very satisfied. We insisted on formal reporting of the trials, according to OECD AHELO indications.

The form of workshop was very interesting and students eagerly organized the work in groups. In particular it was interesting that in the Electrical Technicum (see Fig. 31) students were surprised by this form of lesson: apparently, they did not perform such a work earlier. They were surprised that the voltages can be added (making batteries in series) – getting from a single apple (but more electrodes) as high voltage as 4 V. Joking, we said that they can use such batteries to supply cell phones (obviously, such a simple battery cannot yield enough current intensity).

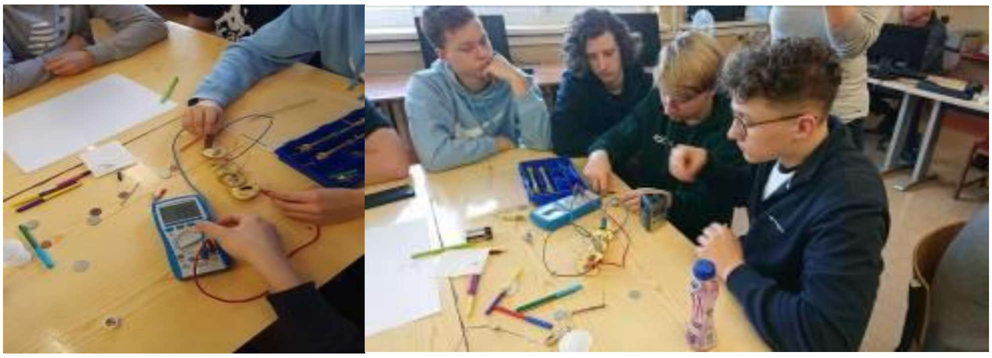

Fig. 31. Workshop at Electrical Technicum in Gdańsk „Volta's vs hydrogen fuel battery", constructing Volta's piles.

The second hour of this workshop slot was devoted to analyzing the construction and function of the hydrogen fuel cell. We used as the explanations the paper prepared by us to Polish "Physics in School" http://dydaktyka.fizyka.umk.pl/fchgo/Samochod_ENG.pdf

The model from "Horizon" is rather simple, and in our personal opinion of modest quality http://dydaktyka.fizyka.umk.pl/fchgo/filmy/Fizyka_dosw_70.mp4

For the advanced lesson we use the model acquired several years ago – from Cosmos-Thames, with a double cell: one acting as electrolyser, another – as a proper FCH, see photo below and the video clip on http://dydaktyka.fizyka.umk.pl/fchgo/filmy/Fizyka_dosw_71.mp4

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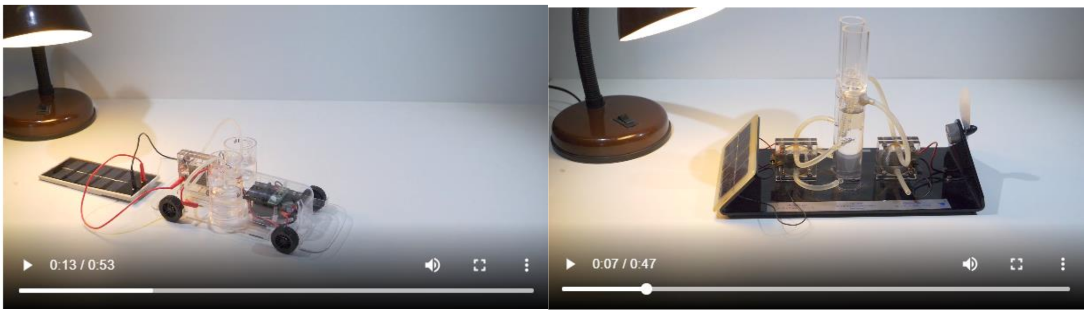

Fig. 32 Comparison of two experimental set ups with FCH used on workshops in secondary schools: (a) Horizon kit, with a detachable photovoltaic cell, connected here to the fuel cell mounted on a toy car. (b) Thames-Cosmos set up, with the PV cell mounted permanently and connected to FCH used as electrolyser; in the middle – containers for H_2 and O_2 (with vertical scale signed); to the right – a second FCH used to produce the electrical current that in turn is supplied to a small electrical motor moving a fan. (Source: UMK)

In spite of the (theoretical) knowledge on the electrolysis and the information that FCH is essentials the inversion of electrolysis, students were quite surprised when the toy car started to move. ☺ In their pre-knowledge they did not associate before that hydrogen and oxygen can operate in the same mode like two different metals in Volta's (or Galvani's) cell.

Fig. 33 Lessons in Electrical Technicum in Gdańsk: „Volta's pile and the fuel hydrogen cell": trials to make the whole process – from light to a moving car – work. (September 2020)

During the lessons next week, the teacher (mgt T. Bury) checked the knowledge acquired by students. Answers to the question "what is the main advantage of using hydrogen fuel cells?" 68% stated that using hydrogen does not emit CO_2, 25% retains that the efficiency of FCH is, potentially, higher than the traditional thermodynamic engines, 7% say that the production of hydrogen is cheap and 5% are convinced that the FCH are simpler in construction than combustion engines.

On the question about the environment, economy and society students answered that alternative „sources" of energy emit less pollution than burning coal or petrol (52%), 38% stated that we develop alternative „sources" of energy because we have no other option: currently available technologies of the energy "production" in the future will not be sufficient to cover need of the mankind as the whole. We develop alternative "sources" of energy because are cheaper than petrol and coal (7% answers) and they do not disturb so much the landscape (6%).

Resuming, FCHgo lessons and workshops in secondary schools (16-17 yrs aged students) turned out to be extremely fruitful. At the "entrance" of the whole FCHgo cycle the knowledge of students on the

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greenhouse effect, global pollutions, air quality, energy “sources”, and available technologies was quite fragmentary. In the Polish context these lessons induced the sensibility against what is frequently invoked in politics the “national industry” that was mining coal. As these young persons soon become voters, their wisdom on environment issues is particularly important.

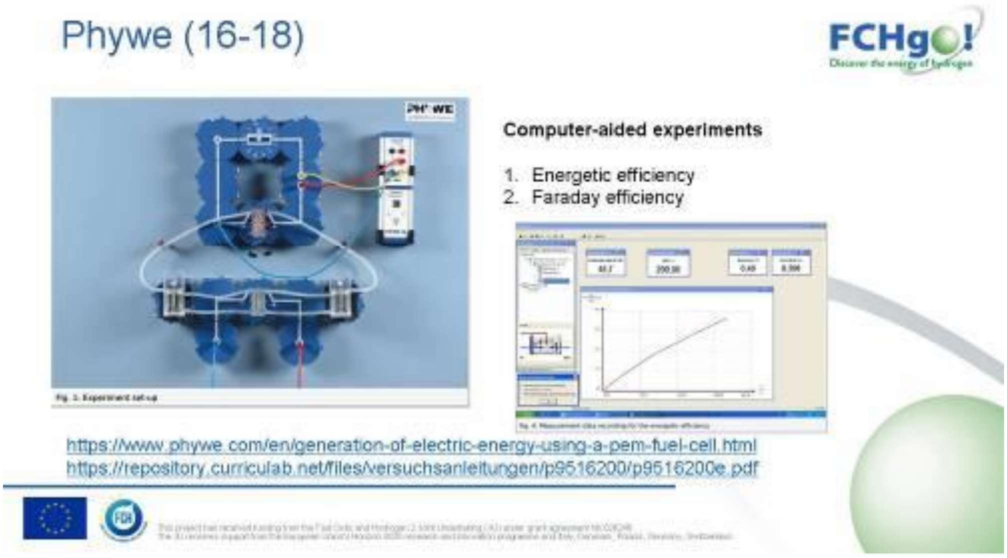
A second important result is the introduction into emerging technologies. Students were surprised that the very principle of FCH working is just inverting the electrolysis. On the other hand, both the university experts and the teachers stressed open technological questions in practical applications of FCH on a large scale. This is also important, as the interest of the future university students can be directed into science and engineering.

Particularly important was also the innovative, narrative method of teaching – not a presentation “ex catedra” but a dialog in which the students discover together different aspects and construct not only a Volta’s pile, but the whole methodology of group working on technical questions.

So, the lessons widened the consciousness of pupils on alternative sources of energy and on the influence of traditional fuels (coal, petrol, gas) on the environment. Students with interest assimilated the knowledge on hydrogen fuel cells and with pleasure were getting involved into the work during lessons and laboratories. They also appreciate an open dialog, in which unresolved technological problems of FCH were discussed.

Detailed reports on the didactical paths from our lesson will be made available on national and international congresses on didactics, and a set of recommended experiments will be given.

Below we present our recommendations for advanced school experiments on hydrogen fuel cells and photovoltaic energy (which we used in our teaching, but they may be expensive for single schools). The choice will depend on the possibilities of single schools: FCHgo staff will assure didactical help in any moment.



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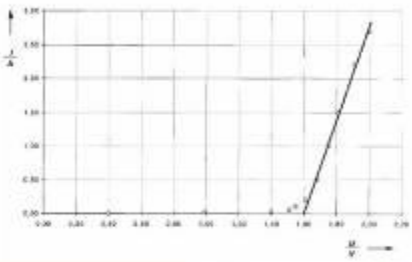
Phywe (13-14)

https://www.phywe.com/en/faraday-and-energetic-efficiencies-of-a-pem-fuel-cell.html

1. Electrolysis in function of voltage, using fuel cell
2. Voltage from fuel cell in function of external load



Recommended, but expensive

https://h-tec-education.com/junior-basic-htec-j101

Contains two separate cells: for electrolysis and generation of current. Very much didactical

Contains only one cell, used both for electrolysis and generation of current. Cheeper

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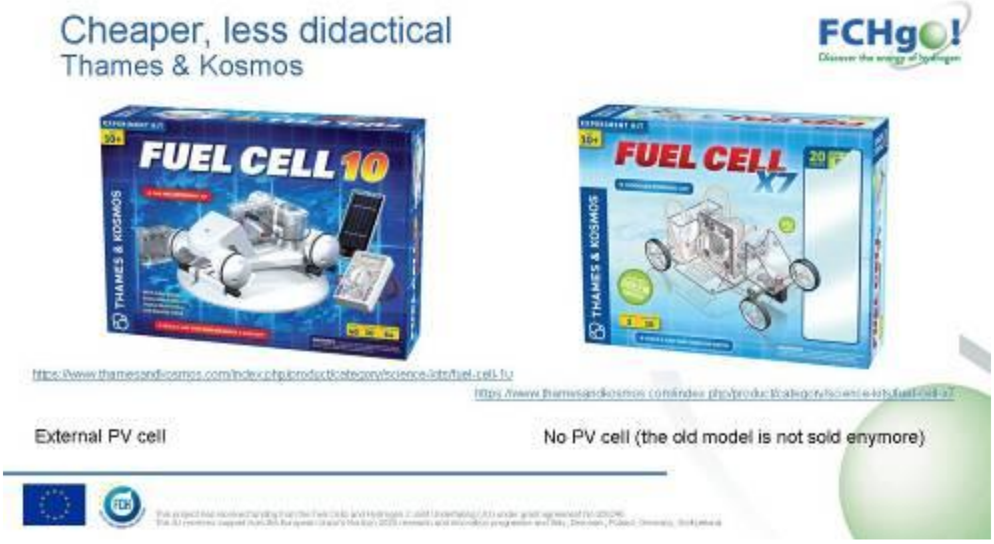

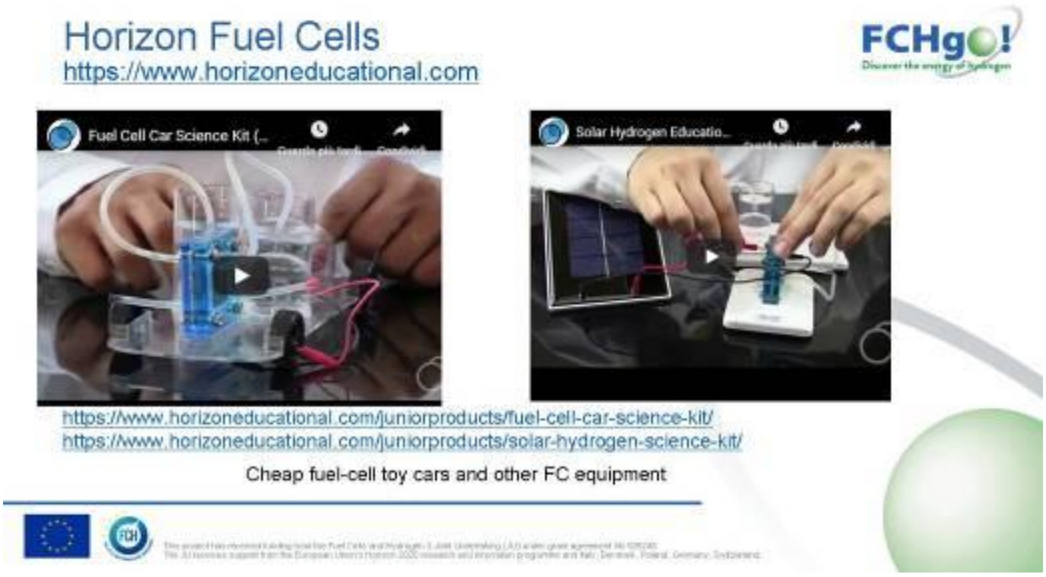

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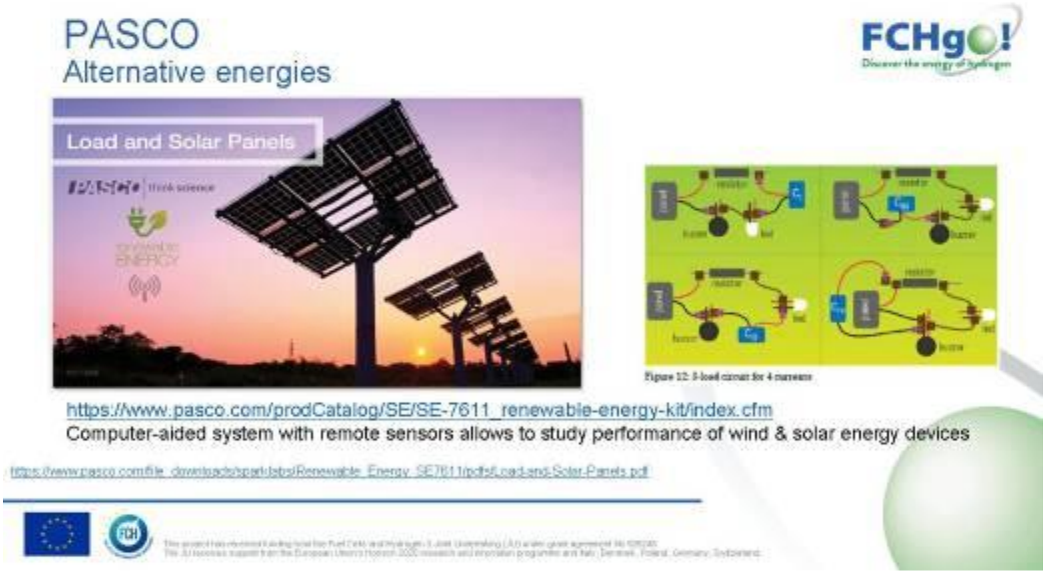

FCHgo influence on students and teacher

MSc Katarzyna Wyborska is teacher of physics, sciences and technical education in two rural schools in Kujawy Region. She acts actively in several social programs aiming to improve the quality of environment (awarded at the national level). At UMK she prepares PhD thesis on innovative didactics. She appreciates much collaboration within FCHgo Project.

The teacher is of great importance in creating students' motivation to learn. A motivated student is eager to learn, strives to improve skills and achieve success in and outside school. Therefore, the basic undertaking aimed at improving my work, and also increasing the quality of school work, is searching for innovative solutions in teaching.

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Every year I am the organizer of a competition on environmental issues in Dąbrowa Biskupia commune. I prepare students to participate in competitions at the county (pl. *powiat*), voivodeship and national level. I initiate and take care of school educational projects and science classes in grades I-III in primary school.

All activities so far contributed to the achievement of measurable didactic and educational effects by me and my students:

- enriching your own workshop by systematically expanding your knowledge and skills; sharing them with students,

- exchanging experiences with other subject teachers,

- engaging in teaching and educational activities of the school,

- popularizing exact sciences among school students.

Each student is gifted for something, has a potential that should be discovered and used. Therefore, introducing students to systematic work on their own development is a particularly important part of the teacher's activities, which supports the development of their interests and talents. Active participation in extracurricular activities is conducive to shaping the personality and developing interests.

All these tasks required from me not only thorough substantive preparation, but also undertaking constant and specific cooperation with selected institutions.

Extremely important in my work is the constant cooperation with the Department of Physics Didactics at the Faculty of Physics, Astronomy and Applied Computer Science in Toruń.

Students of rural primary schools have limited access to modern civilization achievements used during education, that is why it is so important to look for new solutions that will increase the chances of equal education.

Implementation of FCHgo innovation made a huge contribution to energy education in primary school in Dąbrowa Biskupia and Ośniszczewko.

The proposed teaching concept allowed to inspire students to deepen their knowledge of climate change, renewable energy sources and hydrogen technology. All activities undertaken under the project had a common goal, supporting the development of school students, shaping research attitudes and competences through discovery.

The teaching methods used during the project helped to encourage and motivate students to actively participate in research experiences. The teaching content was accessible and understandable to every student at every educational stage.

Students participating in the classes could develop their interest in exact sciences in other conditions than during the lessons. There were completely different forms of work, a relaxed atmosphere, cooperation and the subject matter of classes going beyond the current curriculum, taking into account new technologies. All these factors contributed to the increased activity of the students and awakened their cognitive passion. During the classes, the student could independently observe, compare,

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research, experience and, importantly, ask questions about new technologies. The students performed physical experiments, described the issues surrounding us on a daily basis and discussed physical laws.

Such methods of conducting classes, used as a tool to develop key competences within the FCHgo project!

They are an example of the variety of standard lessons in physics, technology and nature and a move away from traditional teaching. The obvious argument is to shape critical, logical thinking, planning, reasoning, arguing and predicting future decisions. Let us remember that the way of acquiring knowledge or key competences cannot be just a process of communicating information, but should always consist in discovering it - which we have achieved with the methods and tools used in the FCHgo project!

Participation in European projects as FCHgo - Discover the energy of hydrogen, develops my methodological workshop, supplements my knowledge of physics - I am up to date with the latest discoveries, support my development thanks to meetings and participation in many scientific conferences on physics didactics.

4.2 Comments by teacher's consultant

Implementation of FCHgo didactical material in schools – recommendations by dr Krzysztof Rochowicz.

Dr Krzysztof Rochowicz is the researched at Didactics of Physics Division, UMK, and a methodological consultant for teacher in Toruń municipal office.

As part of the FCHgo! project a set of original and varied teaching materials has been developed, which teachers at various levels can use as modern tools and aids that meet the methodological criteria and facilitate understanding the way energy works through stories, play and image [1]. Energy in general and renewables especially are a fascinating subject. Also, young kids in primary school can comprehend the power of energy, if explained with simple metaphors and images. And easily-bored youngsters get excited over chemical and physical processes, if the connection to real-life applications, e.g., in hydrogen storage or fuel cell electric vehicles and their contribution to combatting climate change is made. 'Discover the energy of hydrogen' – that is the claim and scope of the toolkit developed by FCHgo.

The FCHgo toolkit [2] aims at translating simple energy principles for primary school children (age 8-13) and the opportunities of hydrogen and fuel cell technology for secondary school pupils (age 14-18) into ready-to-teach materials, plays and tools for inspiring lessons.

The FCHgo toolkit materials are part of a didactic concept for interactive lessons on energy and FCH developed by the University of Modena and Reggio Emilia, the Zurich University of Applied Sciences, the Nicolaus Copernicus University Torun and the Technical University of Denmark. The content of the materials as well as the outline of the lessons is a result of many years research on the impact of using narrative and metaphors in teaching. The teacher guides describe an exemplary educational path employing the FCHgo materials the best way possible.

The Teaching / Learning Sequence Study „Teacher Guide" provides a brief introduction to the Narrative Approach for Hydrogen and Fuel Cell Technology for primary and secondary teachers and students. The Teacher's Guide is mainly intended for grades 5 and 6 (two additional versions of the Teacher's Guide are for grades 3-4 and for grades 7-8). The path described in this Teacher's Guide is designed to

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assist in the implementation of educational research-based teaching materials. It generally considers the role of energy in natural and technical systems. It begins by reading a story and develops by working with toys, role play with the forces of nature, and producing narratives describing FCH fuel cell systems.

For the youngest, it is the "Apple Story" - a narrative introduction to the subject of food, fuels and energy, as well as concepts necessary for students to intuitively understand the role of fuels in our lives. More precisely, it is a simple illustrated story about a small girl who experiences the magic transformation of blossom to fruit by observing how the tree uses water, air, and sunlight to let apples grow. Pupils learn about storage, transmission and transformation of energy. The story is told by teachers and discussed and played out together with pupils; older students read the story themselves. With help of the story, pupils understand the analogy between energy transmissions from tree to human body via apples and from tank to motion in a car via fuel. The story takes place in an everyday environment and talks about food and natural processes that are familiar even to children aged 7-12. It introduces students to the concepts and keywords used in the next didactic stage. The students' natural curiosity finds an excellent basis here in the form of an engaging, intriguing story.

Thanks to this story, the teacher learns to recognize and apply concepts contained in subsequent, more detailed aids and documents. Analyzing the metaphorical expressions presented in the story, she/he uses the language of children's stories to present everyday life experiences. From a methodological point of view, the Apple Story Analysis guide is extremely valuable, helping to identify the metaphors used when talking about the forces of nature and energy, and the analogies we use in comparing the forces of nature. It is a precious help, especially for beginning teachers and recipients who are not necessarily aware of the main subject of the project. Thanks to detailed descriptions, auxiliary questions and sample attempts to analyze the story, each teacher will feel more confident preparing this lesson.

A very valuable resource for teachers at an early stage of education is the Role Play Guide. It provides ideas for different role-plays in which students act as energy carriers (sun, electricity, heat, hydrogen) and film their performances. With this playful approach pupils experience natural and technical principles with their own bodies and are able to reproduce energy processes themselves. Pupils write a script for their own energy story; they dramatize for example the processes happening in a fuel cell car. This playful approach allows them to experience natural and technical processes with their own bodies. The explanation of the processes taking place in the system of photovoltaic cells and the lamp can be illustrated by means of a representation. The roles played and the materials used should present the processes initiated and carried out by agents - intermediaries as well as the exchange and transfer of energy in the chain of events. Various possible physical systems must be analyzed taking into account their elements and the forces of nature at work within them. Even younger children may be able to come up with a list of the components in the system (such as solar cells, motors, wheels, lamps, etc.) and the forces involved. Older students can create a narrative description of the system's functions. The debriefing discussion questions in the document helps to evaluate the overall activity. This document also contains numerous methodological guidelines important for both the beginner and the experienced teacher.

It may be useful to compare different role-playing configurations (i.e., several plays in which different groups play different forces of nature but in the same arrangement) to highlight similarities and differences among forces of nature. Agents as representatives of the forces of nature can be played by students. In acting as such agents, they would experience a physical equivalent of what those intermediaries would feel if the forces were sentient beings. In other words, they can put themselves

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in their place in our imaginations. The logic behind the physical interactions with our bodies will tell us a lot about how the forces of nature work, what they can and cannot do. The idea of dividing into groups representing different forces of nature will surely be met with a favorable response from children. The use of confetti to represent the amount of energy will help to represent rather abstract processes of energy exchange as natural phenomena that can be visualized. Students who have confetti are in a positive emotional state, and those who do not have confetti are in a negative emotional state - linking emotions with the text being played allows the permanent involvement of memory in the process of learning and acquiring new knowledge. From the methodological point of view, differences in the form of learner involvement at different educational levels are highlighted, leaving also a substantial space for creativity and ingenuity.

Continuing the journey through the world of ideas and their implementation, we reach the point at which physical toys can be involved. Kids examine and compare different toys respective models, for example, a dynamo torch (crank flashlight) and a fuel cell model car, using the work sheet provided by FCHgo. Teachers also receive instructions for the lesson. Through comparing different models pupils learn about their functioning, similarities and differences, while training their analytical skills. Pupils explore each model in groups and describe how it works, before comparing the two models. They describe analogies and differences of processes that are going on in the two models.

Physical toys [see e.g., 3] are an important focus of research by older and more mature students. They enable direct experience with technical devices in which physical and chemical processes can be tested directly.

Even because of its name, the "Teacher Toy Guide" document deserves the attention of teachers. The description of toys in the document consists of two parts: 'How It's Made' (parts and their connections) and 'How It Works' (how they generally work and how parts interact and work together).

There are appropriate sections in the toy worksheets for students. There is a table with energy carriers and connectors (entries suitable for older students are written in italics), as well as process diagrams. When describing items, students are encouraged to pay special attention. In the 'how it works' phase, students are asked to look at the different ways in which these toys work, and it is important to highlight the analogies between some of them.

Methodologically, there is a suggestion to start with small group exploration followed by group comparisons and finally whole class discussions.

FCHgo! Perpetuum Mobile video is a metaphorical fairy tale introducing to the subject of thermodynamics. Using a form attractive for the viewer, it introduces difficult and complex physical topics in a way that is easy to accept and remember. A short, animated movie telling the story of an inventor trying to create a perpetuum mobile consisting of solar cells, pumps, water wheel, and generator. Imaginative 'spirits' – funny looking figures – represent forces of nature carrying energy from interaction to interaction. The movie is used within FCHgo lessons to demonstrate the principle of energy to children. Pupils are introduced to the principles of energy transformation, different forms of energy and the law of energy conservation. Pupils watch the video and analyze together with their teacher the transformation and exchange of energy between the spirits. They learn the name of the 'spirits' and observe that the system only works, if energy is sustained by the sun and heat can escape to the environment.

Energy playing cards is a set of playing cards to 'play through' energy chains in games of domino and speed. The set contains cards for every main energy carrier, including hydrogen. Every card displays a specific intensity to indicate the energy content of the carrier. Pupils learn to correctly identify energy

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carriers and "exchangers" and deepen their understanding for the process of energy exchange, transformation and storage. Kids play different card games, e.g. domino or find the energy carrier, according to instructions and learn about the way energy carriers and exchangers are interconnected.

The comprehensive guide „Introduction to Fuel Cells and Hydrogen Technology" introduces the main principles of FCH technology, using simple language and pictures. The explanations exemplify the approach of FCHgo to teaching energy. The document is intended for teachers and everyone interested in learning more about fuel cells and hydrogen.

To help teachers discussing Fuel Cells and Hydrogen Technology with older pupils, FCHgo partners UMK and DTU developed a set of PowerPoint presentations and videos**.** They provide pupils with facts and background knowledge about climate change, alternative energies and introduce to electrochemistry taking the example of Volta's pile. Also, different applications of fuel cells and hydrogen, e.g. in mobility, are highlighted. By covering social, ecological and technical aspects of the energy transition, the materials foster comprehensive understanding of the issue and prepare pupils for exploring energy science and technologies themselves.

The presentations were used in schools during implementation phase of FCHgo project [4]. Here are some exemplary reflections and ideas after performing lessons in secondary schools in Poland. During the first part, the topic of climate change was discussed, a few simple experiments were performed (e.g. measurement of carbon dioxide concentration, temperature sensor in the evaporation process and in a solar furnace; obtaining hydrogen in the reaction of magnesium with vinegar - observing and describing the properties of hydrogen and its combustion process). The second part of the classes at schools was devoted to discussing selected issues of electrostatics and fuel cells.

Young people showed great interest and knowledge of some aspects of the subject (electricity from the technical side, obtaining renewable energy). Knowledge about global warming, melting glaciers and forest fires is fairly common. As a factor influencing climate change, students mention the increase in carbon dioxide emissions and propose to reduce its emissions, e.g. by replacing old types of stoves with gas stoves and using a bicycle and public transport instead of a car. They propose to limit air travel, meat consumption and plant trees instead of cutting them down. They are also aware of the huge production of plastic and the need to segregate waste.

Based on narrative and playful elements the FCHgo school materials bridge the STEM knowledge gap and teach pupils from 8 to 18 years about the basic principles and applications of fuel cell and hydrogen technology. Overall, the FCHgo activities, from the delivery of teaching materials over their implementation in several European classrooms to the EU-wide FCHgo pupil competition, contribute to build up pupils' STEM competences and prepare them for a fossil-free future.

References

[1] Slota T.S., Young M.F.: „Stories, Games, & Learning Through Play The Affordances Of Game Narrative For Education" (2016), in book: Handbook of Research on Serious Games for Educational Applications; Edition: 1; Chapter: 14; Publisher: IGI Global; Editors: Robert Zheng, Michael K. Gardner.
[2] https://fchgo.eu/toolkit-development/
[3] http://dydaktyka.fizyka.umk.pl/zabawki1/index-en.html
[4] https://fchgo.eu/classroom-sessions/

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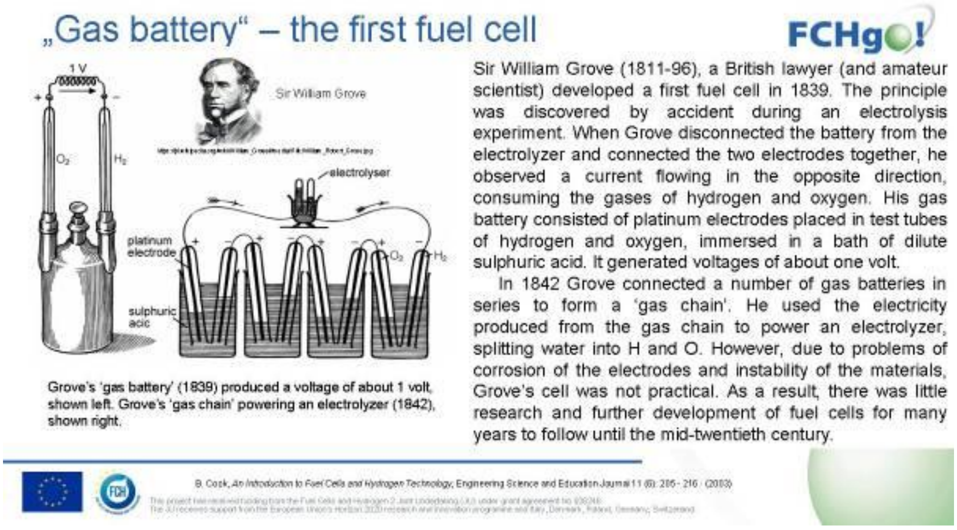
4.3. Comments by university researcher

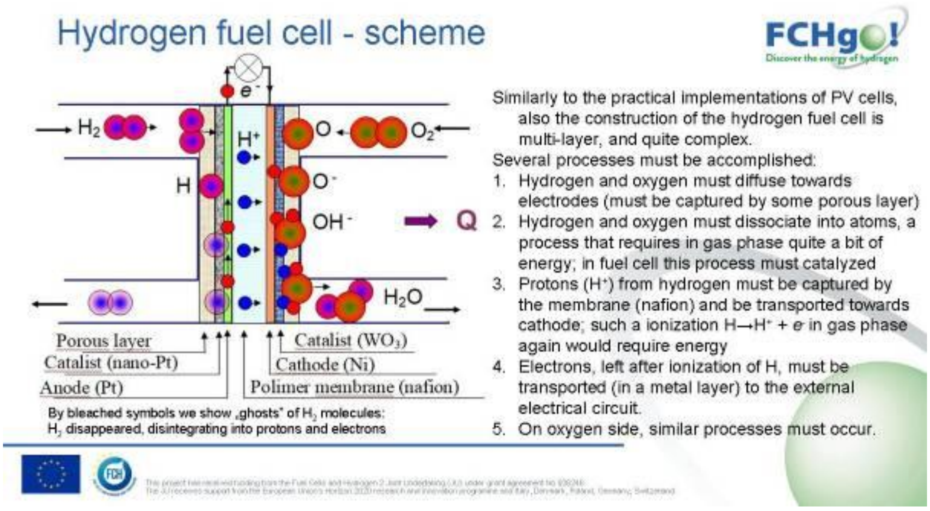
Msc Mikołaj Karawacki is part of FCHgo UMK staff from October 2020. Thanks to this short experience we appreciate his "fresh" view of the Project.

The FCHgo materials' approach towards hydrogen fuel cell technology is detailed but its orientations are rather "utilitarian". The first document prepared within FCHgo (by prof. H. Fuchs) presents fuel cell in somewhat "black box" fashion. The document concentrates on the fluxes of energy streams and only in the final part more attention has been given to the working principles of fuel cells. In this sense several materials prepared at UMK are complementary – lecture by prof. G. Karwasz (three complementary slides are shown below; Fig. 34)

http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/FCHgo_4_Fuel.ppt and the article "Water-driven car" published in "Physics in School" (Polish edition)

http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/860





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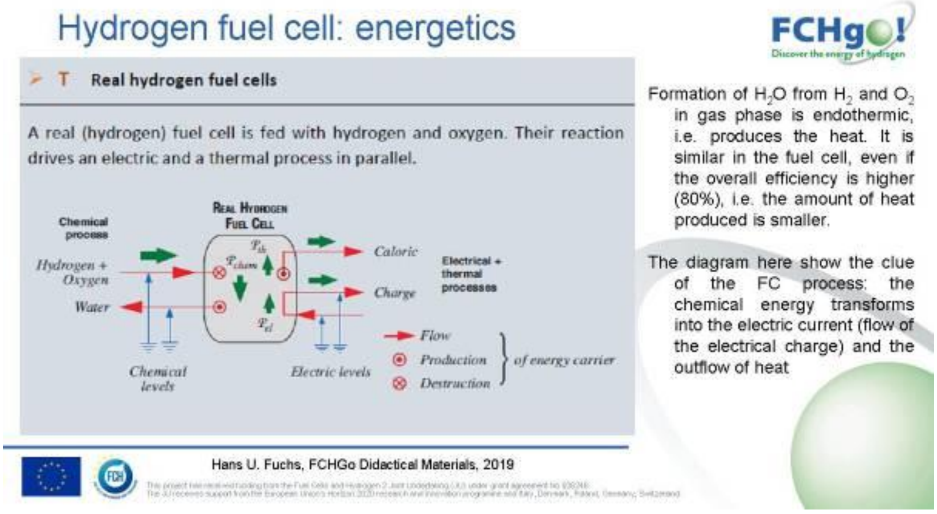

Fig. 34. Three complementary pictures showing how the hydrogen fuel cell works: the historical discovery (William Grove), the principle of construction (picture by G. Karwasz); thermodynamics of FCH (H. Fuchs).

What I find important is to prepare a kind of short manual for teachers on the scientific and technical issues of FCH (apart from the existing presentations, films etc. on FCHgo web sites). It should be an operation manual with comprehensive explanation of the working principles of fuel cells. There should be room given to electrolysis, catalytic processes and electrochemistry, the foundations of hydrogen fuel cells, technical applications and perspectives.

Another point is that the introductory materials on “climate change”, is based on data and information that are at least 8 years old. Why do not include the graph from the paper by FCHgo UMK staff in “Physics in School”?

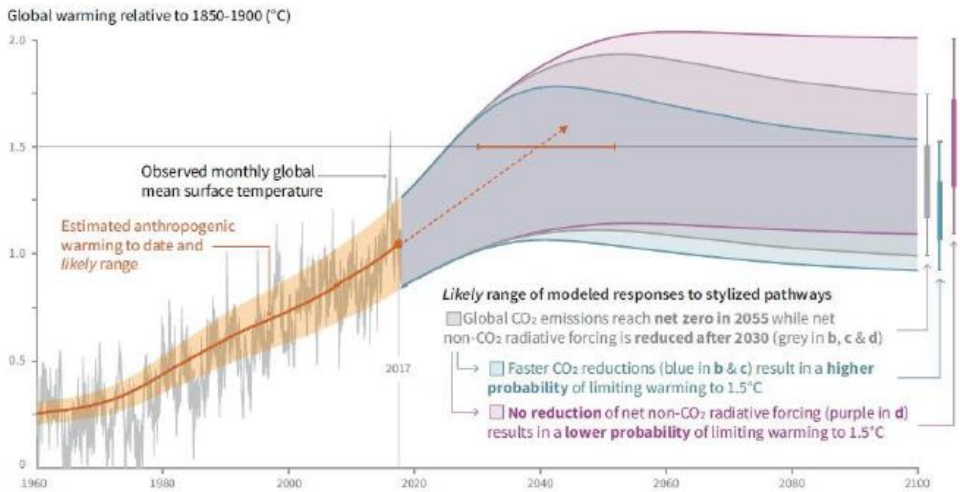

Fig. 4. The most important result of the latest IPCC report on climate change: the expected temperature increase (relative to the pre-industrial era) will be around 1-2°C (depending on the CO_2 emission scenarios) and will reach a maximum around 2050. The model assumes reducing CO_2 emissions to zero in 2055. Source: [4]

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Resuming, I find the FCHgo approach really innovative and I wish it were continued after the Project as well.

4.3 Comments by independent FCHgo observer

Barbara Grazzini works in InEuropa and followed the FCHgo meetings from the kick-off, in particular participated in discussions on educational material and school activities. She is not a teacher, so can be considered an "end-user: of FCHgo "wisdom". She is in charge of WP4 "FCHgo award" We report her (sometimes critical) observations without abbreviations, as they are very precious for the whole follow-up of the Project.

I see things as being an external person, sitting here as if I were a teacher that did not know anything about FCHgo and about the topic and would like to understand … I am thinking what could be useful for this teacher to know, also taking from the EPDM testing experience.

As far as D3.3 is concerned, it is quite exhaustive even if I always need to see summaries in tables, as to have a comparison of what happened in the different countries, also highlighting all at once the Strengths and opportunities of EPDM testing on the one hand, and the weaknesses and threads on the other hand, for different school ages.

There is a mixture of feedbacks on the different countries and a summaries per age groups would be good, also to be published on the website as to give more info to the "new" teachers.

As it comes out of the report, the EPDM is successful but if guided by external experts. Germany is very clear on this point. So how can we make teachers be independent in using it?

I checked on the website, and the guidelines for teachers always state "expert" in the different meetings to be organized in classes for any of the ages involved. How can we then support a teacher if testing is not for all?

How can we engage teachers, if they have guidelines stating that they need an expert? And this also worries me as far as the participation in the award is concerned.

Another aspect that could have been stressed and also published on the website are teachers' feedbacks:

- What did they learn?
- Do they feel comfortable in using the EPDM in classes also without being guided by an expert?
- Will they continue to use the FCHgo approach and materials even beyond the project end? With different classes and students ages?
- Are teachers really engaged in the process?

Unfortunately, I think this is still to be improved in Italy for instance.

In Italy schools for the testing were selected for direct contacts with the general managers. Teachers were invited to test the EPDM guided by UNIMORE experts, but the most of them were not engaged. A top-down approach was used, and the impact is evident now: the classes involved were at their last

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year of the school level, so in June 20 the students would have left for the upper level, changing teachers and maybe the school institute itself. The teachers who tested the EPDM are no more interested to test it in new classes or are not responding to be involved in the FCHgo award. This is a pity. This means that they were reached, trained, but not engaged. And I think this also happened in other countries, not only in Italy. There was not a continuation after the testing, also making activities online for instance or strengthening an engagement also through the award opportunity, beyond the project. This, again, should be strengthened. Maybe it would have been good to have an open call to recruit teachers willing to test the materials from any school, as to have a wider impact, and find what we call "early adopters" that are the best to work with as they are motivated and can guarantee a continuation at any condition.

Collecting feedbacks from teachers by recording them for instance, could have been a good thing to report and also to transfer their experience to others and make other teachers be involved in FCHgo. In addition, when delivering new activities in classes a price or kit would be very much appreciated as a gift for students to have a memory of the activity carried out and for the teacher to use the kit for future activities. For instance, in Water explorer we gave students pencils and shower timers with the project logo, as to make them remember about the project itself and act by saving water at home as well.

Or present the toolkit online also in terms of: easy – medium – high difficulty as to make teachers be able to select and choose and feel comfortable in using the toolkit itself. Diffusion of toolkits on social media, didactical conferences, meetings with teachers must be continued after the Project.

Also, a feedback session could be added to the website to go on collecting teachers' feedbacks, of the ones who are using the materials and are trying to participate in the FCHgo award.

In fact, on the project website only one experience is recorded: (https://fchgo.eu/classroom-sessions/). It would have been good to have one per class level/pupils age and per country for sure. So, we must still work now, and after the Project on the official (and collateral) web sites.

And in this session https://fchgo.eu/news/fchgo-workshops-with-teachers-a-new-approach-to-teaching-energy-to-pupils/ maybe the summary table with the results collected per school age and country would have been appreciated by other teachers. So, maybe a web discussion forum?

I am very concerned about the website, as that is the only tool where FCHgo info are recorded and also materials are uploaded, therefore I think it always needs to be fed and we need to be very practical in the approach and make life easy for teachers as to engage them.

Well, I hope this feedback can be useful, it is not technical, and is very focused on the project as a whole, as I see the project as a whole process in which all steps are very connected, and that can be always improved and needs to be improved to achieve its goals. I know you see it like me. And I would really like also the other partners to have the same approach! Go forwards and backwards to add missing parts and improve it, and also be able to adapt it to the new conditions due to the pandemic.

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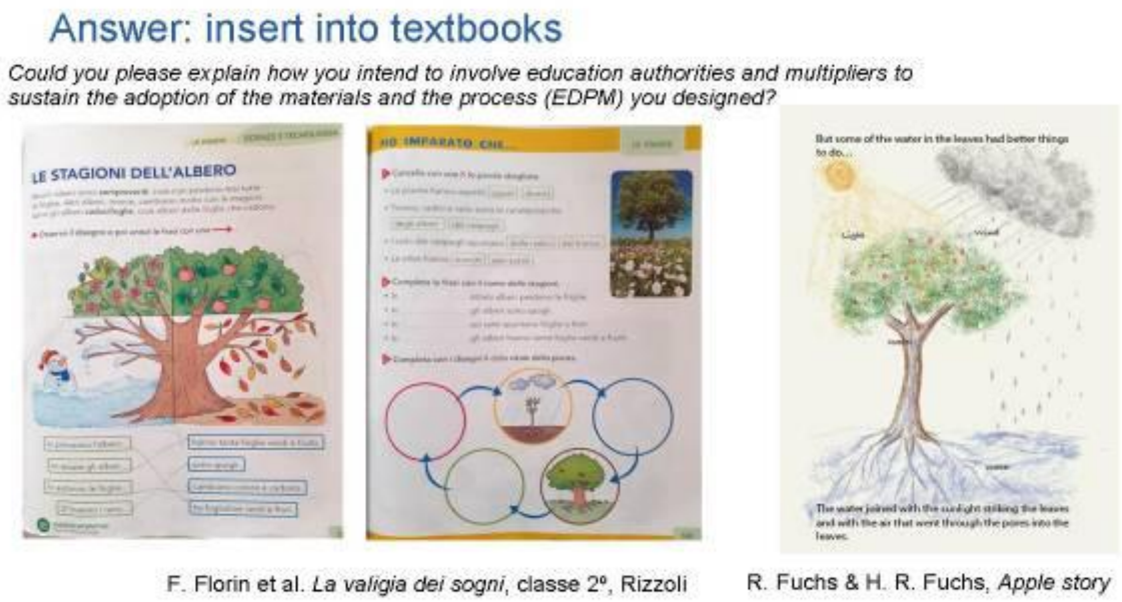
5. Recommendations for FCH teaching strategies

This rapport has been prepared to account for all independent points of view that were gathered by a team of some 60 teachers and researchers involved in the FCHgo implementations in schools. For purpose, we did not search to make uniform these opinions, as any recommendations on the EU platform and on all educational levels for sure will find much more objections and difficulties that we managed to enlist here.

The main difficulty in introducing FCHgo scenarios are differences in national education systems. The social awareness of climate changes and the needs for new technologies are completely polarized, say between Denmark and Poland. Therefore, some actions that seem to be loosely related to the hydrogen fuel cells are absolutely indispensable to assure the success of FCHgo teaching strategies for the future.

Further, teachers in all countries are under permanent stress to perform at the best in changing conditions. We managed to convince a huge number of teachers to test the FCHgo material, but this is mainly thanks to the contribution (also outside the scheduled time) of the FCHgo staff. The question is how can we make the teaching on hydrogen technologies so interesting that it becomes intrinsically part of school cv. One of the suggestions is on the picture below: enlarge the subjects in biology to questions of energy transformations and assimilation, taking as a starting point the "Apple story".



Two strong points of FCHgo strategies emerged:

1) the narrative, interactive approach

2) hands-on experiments.

1. Representation of "forces of nature" as sleeping or traveling "spirits" seemed surprising at the first instance. But as proved by test in elementary school in Switzerland, Italy and Poland it was appreciated, especially at 3rd-4th grades of elementary schools.

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Just at the age of 11-12 yrs we observed a substitution of the metaphor thinking by more technical one. This is an additional reason for a *blended* teaching: metaphor but also practical experiments. The need for experiments holds for all ages.

2. For children (and also to secondary school students) workshops are particularly interesting. Therefore, we must consider some practical solutions for a broad dissemination on (safe and simple) experiments related to hydrogen fuel cells.

School can afford to buy some more expensive equipment containing (see the present report):
- photovoltaic cells
- traditional (incandescent) lamps
- hydrogen fuel cells
- voltmeters
- electrical engines with fans or model electrical cars.

For children any experiment like potato (or apple) battery is quite fascinating. Within material outcome of the FCHgo project we recommend a simple "kit" like that was used in workshops: 3 (or 4) Cu and 3 (or 4) Zn small plates, with LED "positive" end welded to one Cu plate and a short-isolated wire welded to Zn plate. Red LED requires three Cu/Zn pairs, green LED – four.

Playing with "energy transfer" (confetti) is particularly amusing for small children (2^{nd} – 3^{rd} grade). On the other hand, in this age they have still some difficulties in understanding the metaphoric characters of "ghost" – energy carriers. However, already in 4^{th} grade children's artifacts testify that they understand (and enjoy) this metaphor.

At higher grades (5^{th} – 6^{th}) pupils enjoy much different experiments with photo-voltaic driven devices – wind-mills, cars, robots, bugs. A vast choice of these, cheap devices make possible indirect evaluation of the light intensity and the efficiency of PV cells. More – even "not working" devices are useful as a didactical outcome.

In the secondary school, advanced experiments with photovoltaic and hydrogen fuel cells are recommended. A vast choice of possibilities was tested in the FCHgo implementations in schools: it turned out that some complementary experiments can be found even for professional schools (like Electrical Technicum). Several experiments with the chemistry of hydrogen are also possible, where appropriate conditions of security in school laboratories are assured.

Resuming, our recommendation is not a unique scenario, but the vast range of possibilities as tested by teachers (and researchers) in the WP3 of FCHgo.

This vast range of the recommendations that we propose is motivated by the EU indications for education strategies in Teaching Science and Technology (so-called Rocard's Report, 2007): not only consumers, but active constructors of the future.

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Main Conclusions

Resuming the whole 2-year period of implementation of FCHgo teaching scenarios, it proved to be very profitable, not only for students but first of all for teachers involved. The comments of teachers and the questionnaires by students showed that this implementation was not straightforward. At the very first instance the novel methods, i.e. the narrative and metaphoric approach triggered some perplexities among teachers who had been accustomed only with the traditional, transmission-like ways of teaching. However, with proper didactical comments teachers got the main message: different "forms" of energy mean different *carriers*, and hydrogen is one of the most ecological one. Didactical games, cards, simple experiments enriched this message and turned to be particularly appealing to children, starting as early as 2nd grade of the elementary school. The energy conversion scheme that involves the electrolysis of water and hydrogen fuel cell was also understood without problems, once children were able to see it in interactive, simple (and save) models. This success was proven in Switzerland, Italy, Germany, and Poland.

Denmark (and also Poland) developed more advanced scenarios for secondary schools. At that level the important message is that hydrogen technologies, and the questions of renewable energies is not free from open technological questions. Typical misunderstanding is that alternative energy "sources" (photovoltaic, wind) may solely solve the problems with the energy supply. We teach that the energy storage is equally important: this is one of the fields that hydrogen technologies are crucial. Another point is the implementation of hydrogen in transportation. Somewhat luckily, the two regions that we perform FCHgo teaching – High Adige in Italy and Pomerania in Poland invest much in hydrogen-driven transportation (city buses in Bolzano and hydrogen-driven metropolitan train from Gdynia to Hel). The involvement of local industries helped us to develop the net of stakeholders.

From the formal point of view, 1500 pupils underwent FCHgo teaching as compared to 900 planned. Especially in Italy and in Poland the implementations exceeded the expectations. In Italy a second center for FCHgo divulgation, in Bolzano was established and additional teachers, among them of secondary schools were trained with both the material prepared both at ZHAW and UNIMORE ("Energy box", "Perpetuum Mobile", energy games) and at UMK (video lessons on energy, environment, hydrogen, experiments with electromagnetism, photovoltaic and hydrogen fuel cells). In Poland the number of schools that spontaneously asked the access to the hydrogen lesson exceeded the number of schools originally planned. Some 90 teachers in total have been trained in Poland at seminars organized in schools, at UMK, at science centers and on-line during the December 2020 Seminar. Hydrogen technologies were also presented on the biggest Polish dissemination event "Science Picnic" in Warsaw in 2020 (due to restrictions it was on-line). The re-edition is planned for May 2021. Activities in schools have been completed successfully in all five Project countries. Additional divulgation into school environments, also outside the Project countries have been achieved on the three international Seminars on Didactics of Physics and Sciences: on GIREP in July 2019 in Budapest and in November in Malta and on DidSci in Kraków in June 2020.

It was somewhat coincidence, that FCHgo project came in the same period that in the EU new, government treaties for the reduction of CO_2 were signed, countries with the very traditional energetic sectors like Poland entered programs to convert the energy "production" into renewable sources, and

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even the private automobile sectors started a massive conversion to non-petrol technologies. All this means that the educational actions should be intensified – both to rise the social awareness and to prepare scientists, economists, engineers to the new demands. This puts new requirement to the post-project activities: video lessons, in particular with hydrogen experiments – chemistry, physics, and energy conversion will be registered, work sheets for schools published on local didactical sites and via didactical, national journals, and all the didactical material will be made available in 10 languages.

Finally, the activities in schools forced partners to intense exchange of experience and to establish close collaborations that will also continue.

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