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First report on the educational outcome and set of awareness/ efficacy indicators

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PP	Restricted to other programme participants (including the FCH2 JU Services)	
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CO	Confidential, only for members of the consortium (including the FCH2 JU Services)	

CHANGE CONTROL

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DISTRIBUTION LIST

Date	Issue	Group
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List of amendments in the revised version:

- Results of lessons in Italy (pp. 9-12) and Germany (pp. 15-18) added
- Results of on-line comparative tests in Poland (p. 27) added
- Example of filled evaluation questionnaire from Germany added (pp. 39-41)
- Pedagogical aspects discussed (pp. 30-31)
- Possible inclusion of FCHgo results into school curricula proposed (pp. 32-34)

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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 on 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 have been performed, with percentages varying between the five countries involved. This allows 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.

The present update of the report, version 3.1, prepared after the Mid-term review meeting, includes the modifications requested by the referees. Unfortunately, the outbreak of the COVID-19 epidemic blocked activities in schools. In Italy the activities were stopped on February 23rd, in Germany, Switzerland and Denmark a few days later. In Poland, due to winter holidays school activities were stopped at the end of January and did not reprise.

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. 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.

This distribution was slightly modified in the process of implementation, as the number of classes actually increased. In May 2019 adhesion of schools was collected, in August there were signing agreements, while lessons started in October. Changes were caused by several factors.

For example, in Poland, the educational reforms entered in force in 2018/2019: middle schools (11-14 yrs old) were cancelled and the elementary school extended till the age of 13 yrs old (and the upper middle extended from 3 yrs to 4 yrs of teaching). The main problem to the Project was not just the change in ages, but the completely new teaching programmes that entered into practice and the new division of educational tasks as compared the old and new elementary (primary) school. In 2019/2020 teachers in upper middle school teach additionally two age groups – 13 yrs old (within 4 years of Lyceum) and 14 yrs old (3 years Lyceum). It means also that we were forced to modify heavily the contents and scenarios of teaching for all levels in Poland.

2. Schools involved

The list of involved schools and the status of lessons delivered in date 20.02.2020 is as follows:

1) Italy
1a. 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 “Langer”, 1 class, 25 students, 4 x 2 hours lesson (expert)
- Lower Secondary school “Fermi”, 2 classes, 50 students, 2 x 2 hours lesson (expert)
- Upper Secondary school “Torricelli”, 2 classes, 50 students, 3 x 2 hours lesson (expert).

1b. 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 (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)

3) Germany (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 is given in the table further (p. 16).

4) Denmark – activities planned for April 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
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 form, 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)
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.

3. Training materials

Training material for FCHgo has been described in a separate deliverable (D3.2, Training materials for teachers and educators): here we resume only its use on the different levels of teaching (and in different countries).

The basic training material was prepared by University of Modena and Reggio Emilia, Free University of Bolzano and ZHAW, Switzerland. The "master" document describing the subject of Fuel Cells, prepared by prof. H. U. Fuchs is available in English, Italian, German, Polish (the latter at: http://dydaktyka.fizyka.umk.pl/Pliki/FCHGOKR1.pdf). The material is used mainly for teachers training, together with specific teacher guides (https://fchgo.eu/toolkit-development).

In the subject of energy a video by Marion Deichmann is available in German with English, Italian and Polish subtitles (https://fchgo.eu/toolkit-development), and the narration text of the movie is available in English, German, Italian and in Polish (http://www.narrativescience.org/Cases/Cases_Deichmann_02.html) (see also the deliverable D2.2 First version of the educational toolkit).

For schools in Poland we prepared a comprehensive paper in "Physics in School". The paper is available on-line (http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/860) and printed copies are distributed to school where lessons are held.

The set of simple experiments "Energy box" (authors Prof. F. Corni and collaborators) is used in Italy and in two primary schools in Poland (Dąbrowa Biskupia and Bydgoszcz). The outcome of experiments in Poland (pupils aged 10 years) is very positive: in spite of not using the notions of energy, pupils show a vivid interest in the subject).

Due to problems with new, unproved programs in Polish elementary schools we were forced to prepare a mini-cv that introduces the notions of electric current, energy sources, Volta pile etc. This was collected into sets of experiments to be presented (or performed independently by teachers) for different ages: http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/ActivityFCHGo_8_10.pdf (electrolysis), http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/Activity%20FCHGo_11_12.pdf (electrochemistry), http://dydaktyka.fizyka.umk.pl/fchgo/EPDM/ActivityFCHGo_13_14.pdf (electrolysis advanced). Scenarios of lessons on electricity and fuel cells were made available to teachers in English and Polish http://dydaktyka.fizyka.umk.pl/FCHgo2/Electricity.doc, http://dydaktyka.fizyka.umk.pl/FCHgo2/fchgo_FCH_Lesson4.doc, http://dydaktyka.fizyka.umk.pl/FCHgo2/fchgo_alternative_energies_scenario.doc . Some simple experiments at the level of elementary school has been filmed and made available on internet: http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/854

On the level of secondary schools, excluding the teacher guide by UNIBZ and ZHAW (https://fchgo.eu/toolkit-development/), nation-specific lectures were prepared: in Denmark by prof. Anke Hagen (DTU); five lessons (registered at UMK) in Italian are available on youtube: https://youtu.be/Cvwna8FtE4E (Energy and environment) https://youtu.be/h0N3of2nJqU (Volta pile and electrochemistry), https://youtu.be/cgggOm3GGR8 (Alternative energies), https://youtu.be/dlbEz00MEMU (Hydrogen fuel cells) and a lecture on energy, linking to the FCHgo document by prof. H. U. Fuchs https://youtu.be/dEURhjKaQ04, also at http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/857. The latter site contains also these lessons (Power Point presentations) in Polish, English and Italian.

The above-mentioned five Power Points presentations (constitute the main part of lessons for Polish Lyceum, both used by experts and by teachers.

3.1 National priorities

As specified above, the educational material has been adapted to specific national priorities. In Poland there is huge air pollution due to burning coal. Therefore, educational activities on alternative energy sources and technologies are important (see Figure 1).

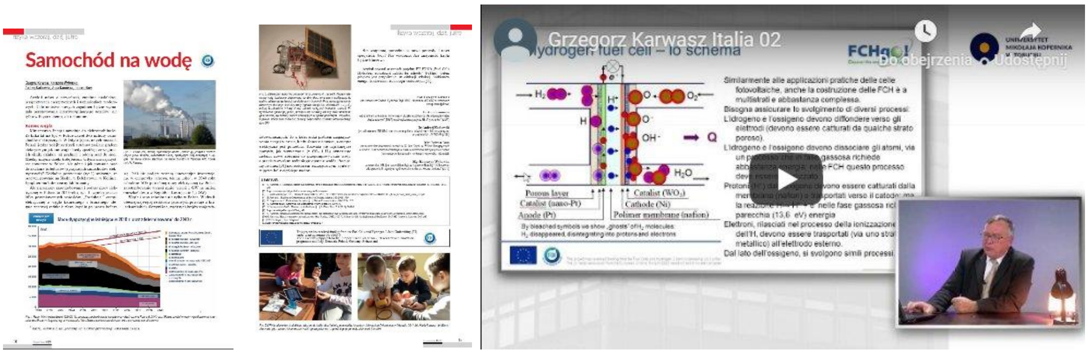


Fig. 1 - Additional educational/ dissemination material produced at UMK: (a, b) “Water driven car” - a paper published in *Physics in School* (1st and 6th pages). (c) Series of 5 lessons registered in Italian and Polish for secondary schools - teachers and students. Lesson No. 4. “Hydrogen fuel cell”, https://youtu.be/dlbEz00MEMU

On the other hand, in the last 20 years, Denmark has converted a large part of the energetic system from burning coal to wind-generators. But this, in turn, creates problems with energy storage: electricity production, hour by hour, does not meet the consumption needs. So, the storage of hydrogen obtained from electrolysis of water would be an important part of the national system (see Figure 2 from Power Point lessons prepared by Prof. Anke Hagen - DTU).

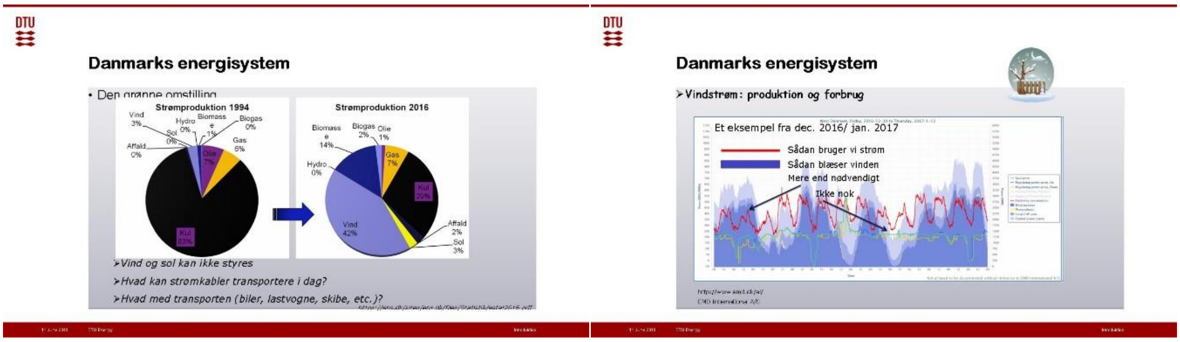


Fig. 2 - (a) Energy “production” in Denmark in 1994 and in 2016: black is coal, blue is wind (Prof. A. Hagen); (b) The demand and supply of energy, day per day in December 2016: they do not meet each other.

Also in Germany it is well understood the need for new energy policies: productions and storage. In Figure 3, we present two pictures from a comprehensive lecture for an international consortium, held in Dresden on August 22nd 2017, by Dr. Johannes Töpler, from Deutscher Wasserstoff und Brennestoffzellenverband (DWV).

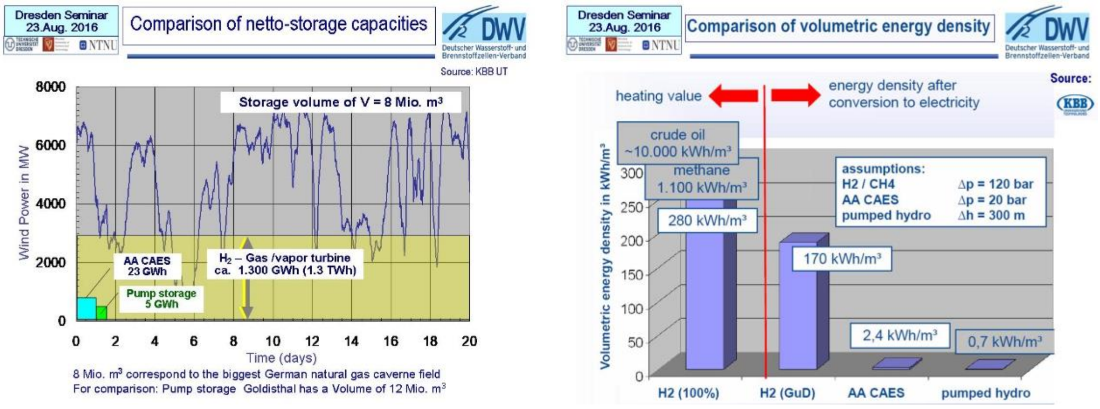


Fig. 3 - Two pictures from presentation by Dr. J. Töpler (DWV) showing: (a) mismatch between wind power and energy storage capacities, (b) storage capacities in water basins, in oil tanks, methane and hydrogen underground tanks. Courtesy: Dr. J. Töpler.

4. Current activities in schools – first results

The evaluation forms on school activities have been prepared (see Appendix I) and are implemented for the evaluation of the educational path.

1) Italy

The educational activities in Italy were performed following the path outlined in the teachers' guide. More specifically, the narrative and metaphorical approach to the study of energy was implemented as described in the deliverable D2.2 and D3.2.

a) <u>UNIBZ</u>: a first group of activities in Bolzano has been delivered in December 2019 (other activities are planned for January and February 2020):

- Primary school "Langer", Bolzano: 1 class (5 A), 25 students, 2 x 2 hours meetings led by the expert (Prof. F. Corni) (Figure 4).
- Lower Secondary school "Fermi", Bolzano: 2 classes (3 A and 3 C), 25+25 students, 2 x 2 hour meeting led by the expert (Prof. F. Corni).

The status of teaching done in Bozen, in date 15/02/2020 was as seen on figure 4.

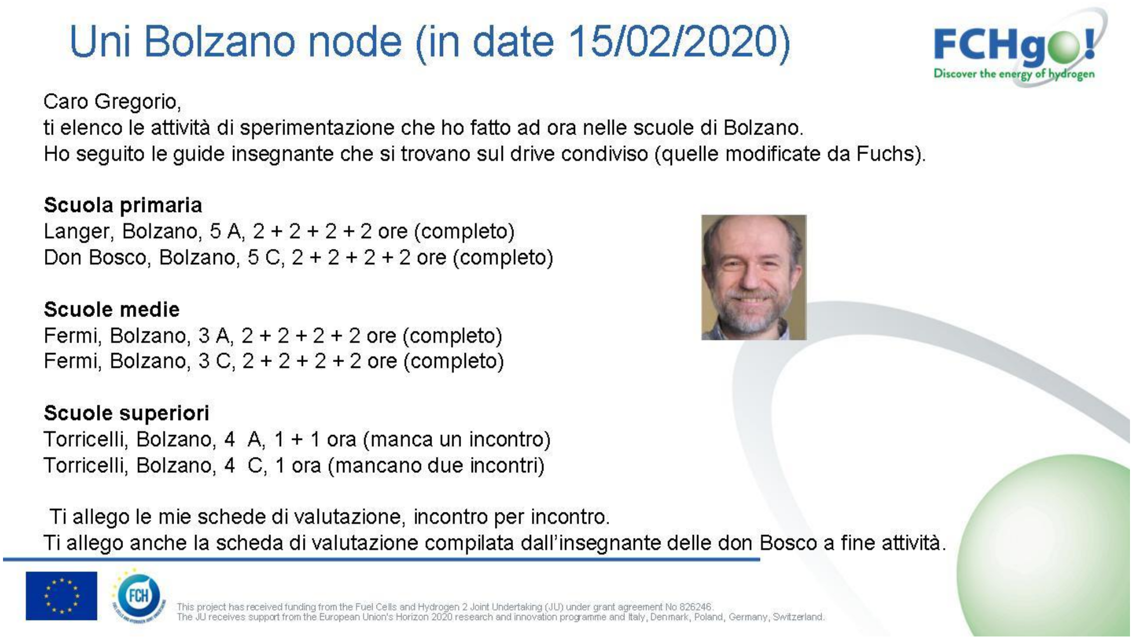


Fig. 4 - The status of teaching in Bolzano node, as in date 15/02/2020.

In the elementary school, 3rd class (aged 8-9) some hydrogen "toys" were tested. It was revealed that these toys are *not* completely intuitive: descriptions by some students were very general, showing that they have not understood its functions and they do not use an appropriate language for their description. The very concept of energy needs a somewhat better explaining. In the conclusion (see Fig. 5) the card game is left for the teacher.

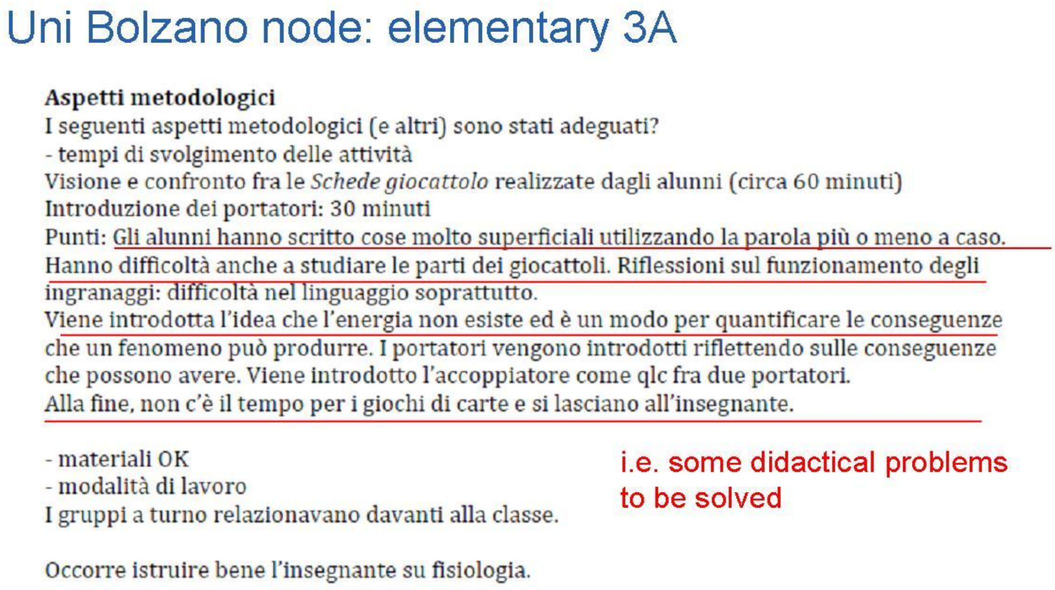


Fig. 5 - First report on teaching the concept of energy and its carriers and the functioning of hydrogen "toys". Report from Prof. F. Corni: the general scheme of lesson was kept correctly, but pupils reported some aspects in a superficial way. They have difficulties in understanding the functions of the hydrogen "toys": these are mainly difficulties in the correct verbal expressions. The idea of energy has been introduced: pupils understood the function of energy carriers. But at the end, no time was left for the card games.

The snapshot on the pedagogical issues is given in Figure 6. Pupils do not appear much spontaneous on these photos, and they, probably, find the subject somewhat above their possibilities.

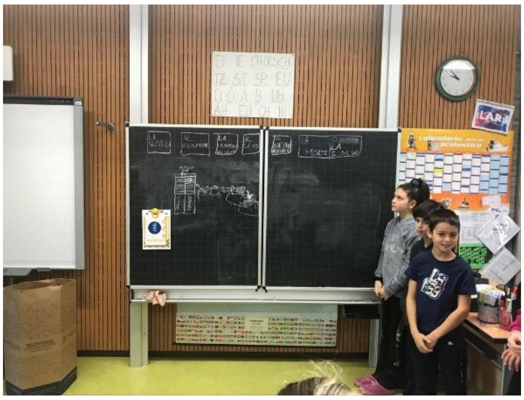
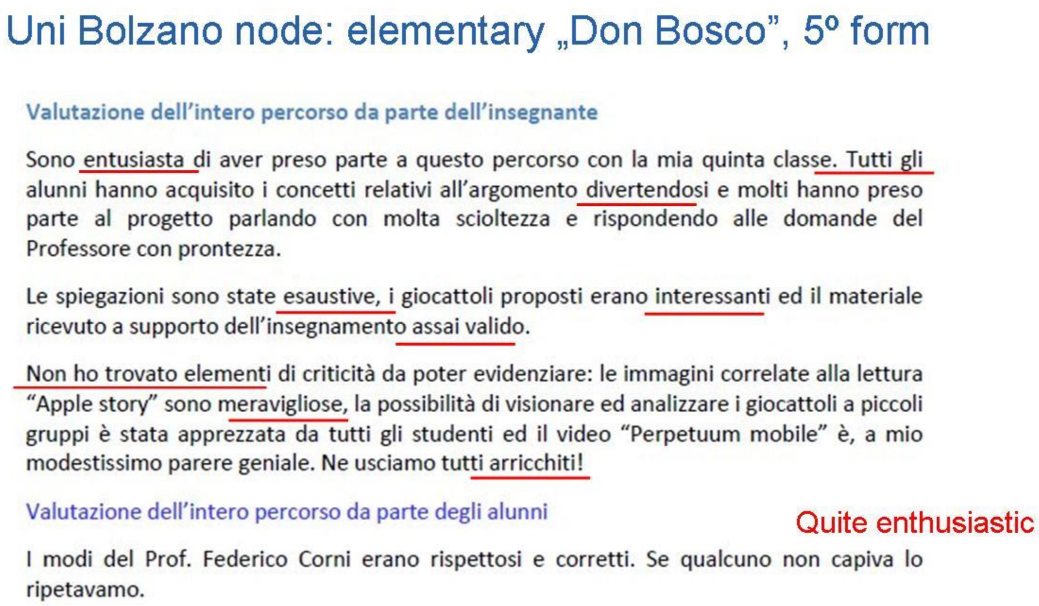


Fig. 6 - Snapshots from the teaching sequence, 3rd class, elementary school "Langer" in Bozen, Italy. Pedagogically, it can be noticed that pupils have to discuss and are less spontaneous than in the small village in Poland, Dąbrowa (see Fig. 17). Photo by F. Corni.

The didactical outcome was better in 5th class of elementary school (aged 10-11). According to the teacher, pupils were enthusiastic being able to play freely with hydrogen car, photovoltaic cells, and "hand" dynamo. The didactical material, including the film on "Perpetuum mobile" was valid, and the "Apple story" was defined as "marvellous". The original report of the teacher is given in Fig. 7.



Uni Bolzano node: elementary „Don Bosco", 5º form

Valutazione dell'intero percorso da parte dell'insegnante

Sono entusiasta di aver preso parte a questo percorso con la mia quinta classe. Tutti gli alunni hanno acquisito i concetti relativi all'argomento divertendosi e molti hanno preso parte al progetto parlando con molta scioltezza e rispondendo alle domande del Professore con prontezza.

Le spiegazioni sono state esaustive, i giocattoli proposti erano interessanti ed il materiale ricevuto a supporto dell'insegnamento assai valido.

Non ho trovato elementi di criticità da poter evidenziare: le immagini correlate alla lettura "Apple story" sono meravigliose, la possibilità di visionare ed analizzare i giocattoli a piccoli gruppi è stata apprezzata da tutti gli studenti ed il video "Perpetuum mobile" è, a mio modestissimo parere geniale. Ne usciamo tutti arricchiti!

Valutazione dell'intero percorso da parte degli alunni

Quite enthusiastic

I modi del Prof. Federico Corni erano rispettosi e corretti. Se qualcuno non capiva lo ripetavamo.

Fig. 7 - The report from the lesson on hydrogen car, energy transformations and "Perpetuum mobile" from 5th class in elementary school in Bolzano. The teacher says to be enthusiastic; all pupils acquired the appropriate concepts playing with pleasure, and promptly answering the questions of the professor. The explanations were exhaustive, the experiments "toys" interesting and the didactical material quite valid. Teacher does not find critical elements: the "Apple story" is marvellous, the possibility of examining the "toys" was appreciated and the video "Perpetuum mobile" in her opinion is simply genial. They were all enriched.

b) UNIMORE: activities have already started (or will start in February 2020, see also Cap. 2 – Schools involved)
Primary school D. D. 1 Formigine (Modena): a total of 4 classes and 85 students are involved. More specifically:
- "G. Carducci" school (Formigine): 1 class, 24 students, 4 X 2 lesson hours (FCHgo expert, Dr. Paola Morelli) planned from January to February 2020 (two hours of lesson were made as online due to the lockdown).
- "Ferrari" school (Formigine): 3 classes, 61 students, 4 x 2 lesson hours (FCHgo expert, Dr. Paola Morelli) delivered in 1 class, and planned in 2 classes from January to February 2020.

Lower Secondary school: Distretto Didattico "A. Fiori" (a total of 4 classes and 90 students are involved). More specifically:
- Formigine (Modena): 2 classes, 44 students; 4 x 2 lesson hours (FCHgo expert, Dr. Paola Morelli) delivered in December 2019.
- Magreta (Modena): 1 class, 20 students; 4 x 2 lesson hours (FCHgo expert, Dr. Paola Morelli), planned to be completed in February 2020 (two lessons were cancelled due to the lockdown).
- Casinalbo (Modena): 1 class, 26 students; 4 x 2 lesson hours (FCHgo expert, Dr. Paola Morelli) planned to be completed in February 2020 (the last two hours made as online due to the lockdown).

Photos from the lessons on hydrogen car and dynamo torch at Formigine (Modena) are shown in Fig. 8 and student's reports in Fig. 9. Students analysed in detail components and the functionality of "toys" – their descriptions are complete and use a correct language of physics; their laboratory work shows a clear, spontaneous division of tasks.

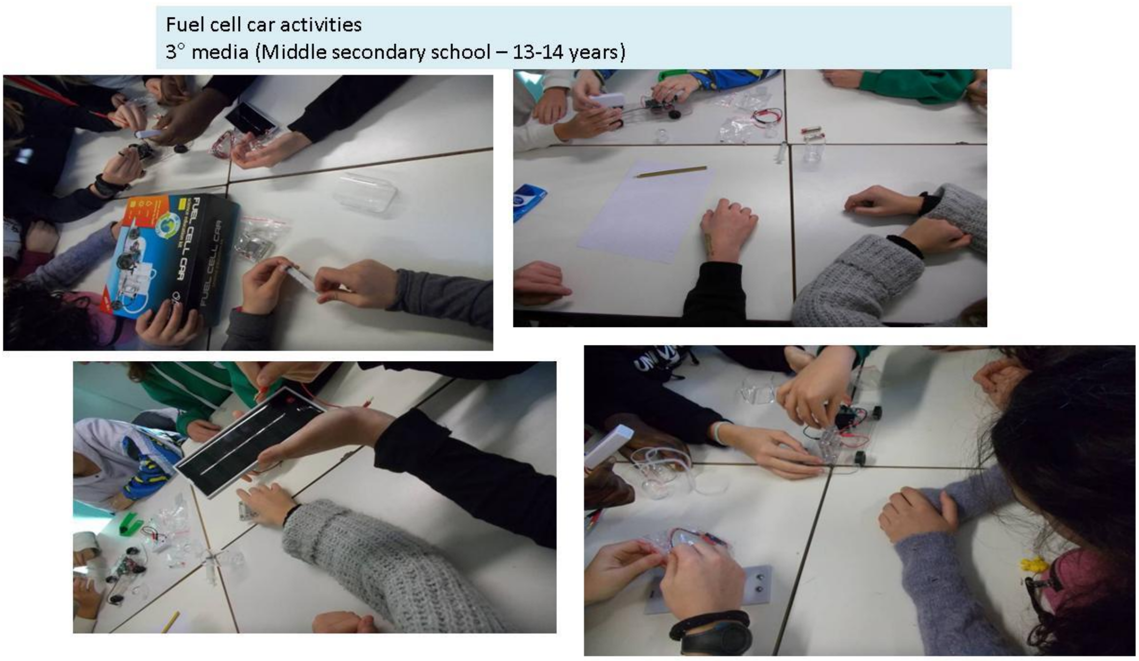


Fig. 8 - Photos from 3rd class middle school (13-14 yrs old) in Formigine (Modena): pupils organize spontaneously the division of tasks.

The working conclusion from the comparison of Figs. 6 and 8 is that, probably, for the elementary school a different narration on hydrogen car has to be prepared. For the middle school a more complex didactical material is needed. Probably, a dissemination paper in Italian "Fisica a scuola", like that shown in Fig. 1 should be prepared. In the 3rd class of middle school students know well elements of physics (states of matter), chemistry, including the electrochemistry and Volta series. Concepts like energetic efficiency and the energy dissipation can be introduced. More quantitative experiments could be introduced. It would be also interesting to test specifically the understanding of "Perpetuum mobile" at this level of education.

On the other hand, the Italian experts state that "Apple story" works very well in the elementary school but it is not so appealing in the middle school: another type of narration should be developed, corresponding better to their level of scientific knowledge.

Fuel cell car activities
3° media (Middle secondary school – 13-14 years)

Dynamo torch

Fig. 9 - "Dynamo torch" descriptions from 3rd class students of middle school ("Fiori", Formigine, Modena). Descriptions are pretty correct, even if the student says "electric movement" instead of "electric current". Expert: dr. Paola Morelli.

2) Switzerland

Two experts (Dr. Elisabeth Dumont and Prof. Hans U. Fuchs) had 6 classes from local primary schools in January/February for a lab session of 3 hours per class. They are primary school pupils, age 8 to 10 years, with about 20-25 pupils each. That was from 120 to 150 pupils. Every class was hosted one morning in the lab at ZHAW. In total 36 hours were held by FCHgo staff. The experimental equipment has been bought through ZHAW.

Lessons started in January 2020. On January 8th Erwin Huonder visited ZHAW with his 4th grade of primary school Altstadt/Lind, Lindstrasse 1, 8400 Winterthur. The kids had just learned about electricity and heat at school. The lesson started with the movie Perpetuum Mobile and pupils discussed the "ghosts", which appeared in the movie. The kids recognized quickly electricity, heat, rotation ("Bewegung") and light. They drew the ghosts on the blackboard and named them correctly (Figure 10). The kids got a poster and playing cards with the ghosts. Experiments were performed for understanding energy using copper and zinc for the potato battery (Fig. 11a, b), and hydrogen and oxygen for the fuel cell (Fig. 11c). An example of the narration of the experiments by a pupil (Lea) is depicted in Figure 12. The first experience was very positive, the teacher and the kids liked it very much (Figure 13).

Fig. 10 – Class activities at ZHAW, Switzerland, January 2020. The narration is based on “energy spirits” from the video “Perpetuum mobile” by M. Deichmann. Placing them on a blackboard allows to make a better sequence of events in the photovoltaic cycle. Photo © E. Dumont

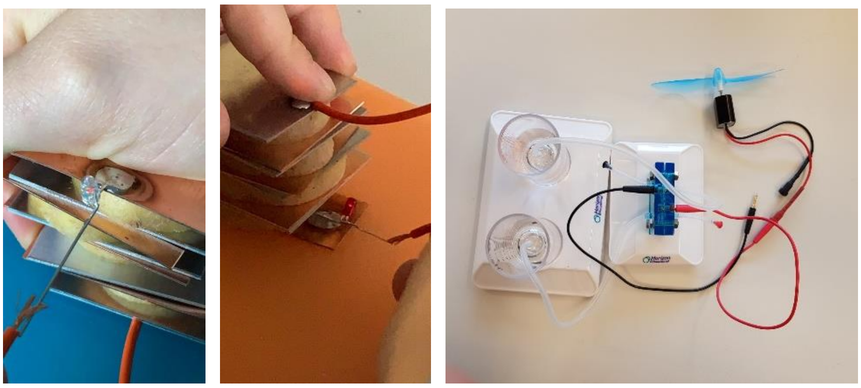


Fig. 1 – Experiments performed at ZHAW, Switzerland. Left and Centre: potato battery; right: hydrogen fuel cell. A clear analogy can be taught. Photo © E. Dumont

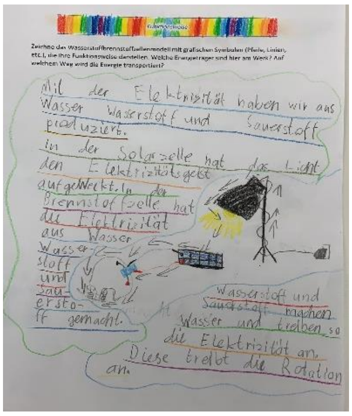


Fig. 12 – Narrative description of the experiments by Lea. She uses correct expressions like “electricity”, “solar cell”, water (Wasser) and hydrogen (Wasserstoff). Probably, the similarity of these words in German makes easier understanding of the transformations in hydrogen fuel cell. This experience will be shared with other partners. Photo © E. Dumont

Fig. 13 - The final photo after the lesson from 4th grade primary school class of Altstadt/Lind, Winterthur, Switzerland, with the FCHgo expert Dr. E. Dumont. Photo © E. Dumont.

3) Germany

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”. In appendix 2 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
Freie Aton Schule München (elementary and middle school)	January/February 2020	5th class 14 children	According to lesson plan of UNIMORE for primary school pupils, age 8-13

Teachers appreciated the new pedagogical approach and the technical contents, as we show in Fig. 14, quoting their original correspondence.

Implementation: Germany (elementary schools) S2i/ Agado (Sandrina Felder)

STRUCTURE AND EXECUTION OF LESSON

_Children are looking forward to the workshop and are genuinely excited
_they are motivated and look forward to exploring the topic with a new person
_can draw on previous knowledge in the field of energy

After a short round of introductions we asked the children a few questions about the topic of energy, all of them can say something about it due to the preliminary work of the teacher
_in advance we had painted a blue drop of water on the blackboard, filled with white (oxygen) and green (hydrogen) balls. Together we discussed the terms 'element', 'hydrogen', 'oxygen' and 'molecule' and think of a nickname for the water, i.e. 'H2O'.

We play 'Simon says:...' to consolidate the 4 learned terms, which is great fun for the children, so we play 2 rounds
_then I (the teacher) would explain the functional principle of the hydrogen car with the help of a schematized fuel cell [Agado prepared a paper model of a fuel cell]
_with the help of metaphors like: membrane=sieve, hydrogen=water, oxygen=noodles, the children can quickly understand the principle of operation and reproduce it independently

Implementation: Germany (elementary schools) S2i/ Agado (Sandrina Felder)

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Fig. 14 - The correspondence from the teacher of elementary school in January 2020, after the first lessons of FCHgo. She appreciated the technical contents and the new pedagogical approach.

However, all German teachers were rather sceptic on details of teaching scenarios. Here we quote the opinions of two teachers (underlined by G. Karwasz).

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 centre 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.

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.

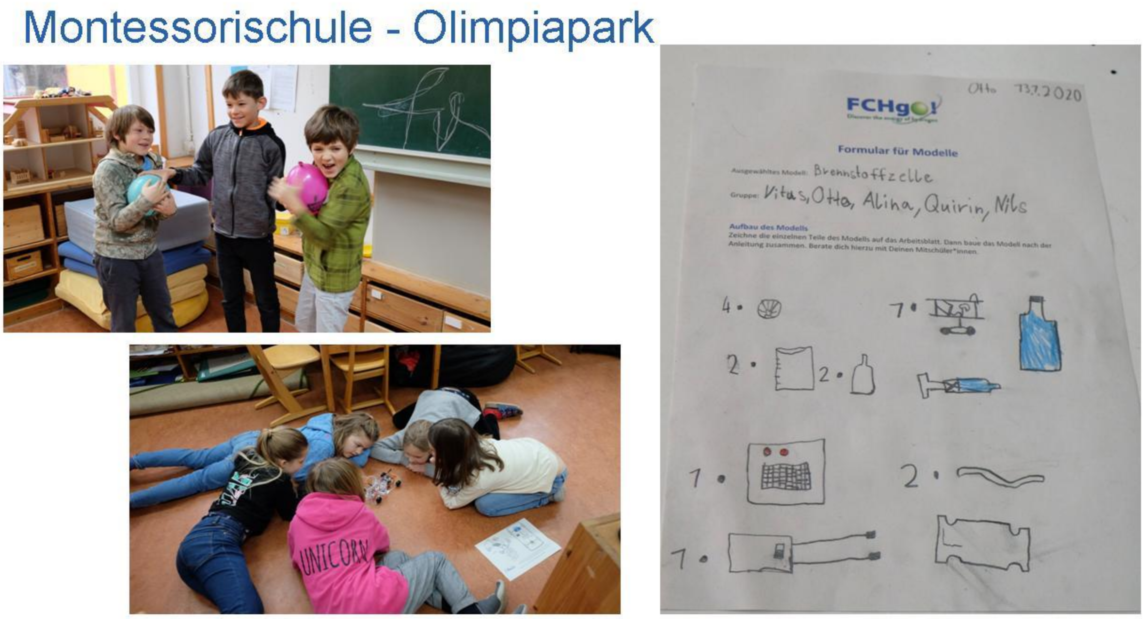

Fig. 15 - Pedagogical aspects of the FCHgo workshops in German elementary school: enthusiastic playing with objects and games.

4) Denmark

Before the start of teaching activities, an intensive exchange with teachers in various Danish schools was done. They pointed to the following needs for their teaching in fuel cells and electrolysis:

- Missing information about the overall energy system, with particular focus on the Danish situation.
- General teaching approach of illustrative / experimental presentations, including discussions involving the students (activation).
- Cross topical teaching.

Based on this input DTU has developed additional Power Point presentations, which also include discussion / questions during the presentations and showing an experiment. The specific fuel cell type we selected is represented by high temperature cells, because that fits very well with our research (we include such research as well but have not attached here) – the material can be made for low temperature fuel cells as well.
Lessons in 3 Danish high schools are under implementation, using the expanded didactical material.

5) Poland

The state of teaching at date 12 January 2020 is that 1/3 of lessons (2 hour 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 (Figures 9 - 11). 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 will be longer than predicted, even if 6 experts are employed simultaneously in the itinerary lessons.

Fig. 16 - Activities in Poland for elementary schools (Dr. K. Rochowicz, in Bydgoszcz) and secondary schools (Lyceum in Grudziądz, Dr. hab. K. Fedus). Experiments and Power Point presentations are used. Photo © FCHgo! Project

Fig. 17 - Activities in 1st and 2nd classes (7-9 yrs old) in primary schools in Dąbrowa Biskupia and Ośniszczewko (Dec. 2019). Teacher: Kasia Wyborska. Photo © FCHgo! Project

Fig. 18 - FCHgo activities in secondary schools in Poland: (a) First lesson with experts in LA Słupsk, 18/10/2019 (G. Karwasz, A. Kamińska) – Introduction to environment and energy problems. (b) Alternative energies – Interactive experiments (IX LO Gdynia, 22/11/2019); teacher T. Bury, experts A. Kamińska and G. Karwasz. (c) Students' attendance (54 persons) I LO Gniezno 25/20/2019; expert G. Karwasz. Photo © FCHgo! Project

5. Experts' evaluation

By February 15th the first run of lessons has been concluded in Bozen, some schools in Poland, in Germany and in Modena. Here we quote some additional opinions of university experts. An example of a full questionnaire by a teacher of elementary schools in Germany is given in appendix II.

High secondary schools

Dr. hab. Kamil Fedus, prof. (UMK)

Students (from high school) listened to a lecture on climate changes and all anthropogenic factors affecting the natural environment - including those factors associated with energy production. Hydrogen-based energy sources have been presented as eco-friendly alternatives for contemporary energy sources. In particular, the fuel cells using hydrogen as a fuel were described as the prospective energy sources for supplying the world with clean, sustainable electrical power. In particular students were interested in hydrogen car and all aspects of its operation.

Dr. Anna Kamińska (UMK)

Students know quite a lot on the problems of environmental pollution, on climate changes, they know in what these changes consist, what they are caused by. They also know that urgent actions must be undertaken, but they do not know what they can do themselves to mitigate environmental pollution. They ask when hydrogen cars will circulate on urban streets.

Primary schools

Dr. Andrzej Karbowski (UMK)

In classes conducted at the Primary School in Dolna Grupa as part of the FCHgo project, students from classes 8 (14 years old) were very interested and active. They were happy to answer their questions and share their knowledge with other students. They loved the way the classes were conducted, during which a lot of experience was presented and the applications of the discussed physical laws in energy, environmental protection, technology and science were discussed. The students learned notions on electrostatic voltages, electrochemical voltages, generation of electric current by induction and in photoelectrical devices. The pupils achieved new social competences during classes and learned that when working with various electrical devices very important is safety of people.

Dr. hab. Kamil Fedus (UMK)

Students (from primary school) were strongly interested in the methods of producing electricity. They were taught that mechanical, chemical and light energies can be converted into electricity used to power houses, cars and all electrical devices. They knew very well batteries as sources of electricity necessary for cell phones and small appliances. They also knew that power plants provide electricity to electrical mains in houses, but they did not know how this electricity is produced. There were very surprised that moving magnet induces electric current (through electro-magnetic induction) in a simple copper wire connected to diode. They could not name drawbacks of using "traditional" coal power plants such as climate pollution and greenhouse effect. They could give example of renewable energy sources (sunlight, wind, rain), however they have not heard before about hydrogen fuel cells. It was the first time when they met with this concept.

Dr. Paola Morelli (UNIMORE)

The narrative and metaphorical approach on energy has been successful for younger pupils. The Apple story, the Perpetuum mobile video, Card and role playing games and the Fuel cell model car were helpful to raise interest and involvement in scientific topics, especially for alternative energies and fuel cell hydrogen. Nevertheless, some materials have to be adapted to the age of older pupils (13-14 yrs old).

6. Preliminary tests

Secondary schools

In Poland only 3 secondary schools finished the cycle of 4 lessons x2 hours by January 2020. The questionnaire and the responses from 3 schools are shown below, where vote (5=much, 1=none) and number of answers for each vote are reported.

1. Did you gain new information on climate changes during FCHgo lessons?

Vote	5	4	3	2	1
III LO Słupsk	3	5	1	0	0
ALO Słupsk	5	9	1	1	0
IX LO Gdynia	2	8	3	1	0

2. Were the experiments on alternative energies interesting?

Vote	5	4	3	2	1
III LO Słupsk	4	3	1	1	0
ALO Słupsk	3	8	6	1	0
IX LO Gdynia	2	8	7	1	0

3. Do you know what are the difficulties in practical implementations of “alternative” energies?

Vote	5	4	3	2	1
III LO Słupsk	3	3	2	1	0
ALO Słupsk	7	2	2	5	2
IX LO Gdynia	1	5	6	5	1

4. Does “water-driven” car has technological future?

Vote	5	4	3	2	1
III LO Słupsk	1	2	5	1	0
ALO Słupsk	4	2	4	6	2
IX LO Gdynia	1	9	5	2	1

Questionnaire results (below). Numbers of answers from the three schools are given: the sums are higher than number of pupils as we permitted more than one answer for each question.

A. Which sentence is correct?

1. The climate on Earth is becoming warmer because of the changes in the energy emitted by Sun. **1/ 4 / 3**
2. The main greenhouse gas on Earth is CO_2. **0/ 12 / 15**
3. The level of CO_2 in last 400,000 years was constant. **8/ 7 / 11**
4. The atmosphere is transparent for the infrared light. **0/ 0/ 2**

B. What is the main advantage of using hydrogen in fuel cells? Choose the best answer.

1. Hydrogen is cheap to be produced. **0/ 2/ 2**
2. Burning hydrogen does not emit CO_2. **9/ 9/ 7**
3. Efficiency of fuel cells is, potentially, higher that burning hydrogen in combustion engines. **0/9/ 5**
4. Fuel cells are simpler in construction than combustion engines. **0/ 0/ 2**

C. Which statement is the most appropriate?

1. We develop alternative energy "sources" because they are cheaper than oil or coal. **0/ 2 /2**
2. We develop alternative energy "sources" because they emit less pollutants than burning coal or petrol **7/ 5/ 18**
3. We develop alternative energy "sources" because there is no other choice: available currently technologies of energy "production" soon will be not sufficient for the humanity as a whole **0/ 11/ 1**
4. We develop alternative energy "sources" because they do not disturb the landscape. **2/ 1/ 1**

D. Which argument for abandoning burning coal in Poland is the most important?

1. Rising of the mean temperature on Earth (global warming) **7/ 10/ 19**
2. High social costs of coal mining **1/ 2/ 1**
3. Absolutely excessive levels of benzopirene in air in winter **3/ 12/ 3**
4. Landscape disturbance by smoking chimneys from households **2/ 8/ 2**

The above results show that students of secondary schools understood well the main message from FCHgo, as profiled for Poland: the necessity of climate mitigation and local air protection, and that hydrogen technologies could be important, but are not an immediate solution. However, some improvement of the information contents and/or of experiments is also needed.

Primary schools

The reform of the educational system in Poland forced the need for modification of training material: after the rupture of school programmes there is no basis on which FCHgo advanced notions can be taught. Therefore, first series of lessons (practically the first encounter with Physics for pupils) in 7th (and 8th) form was on the basis of electricity ("sources of electricity") and on the states of matter (properties of gases). Alternative sources of electricity, like photovoltaic, model of wind and water-powered generators were also shown.

The valence of tests is, therefore, quite limited. In appendix 1 we list the question of the pilot test run in Dąbrowa Biskupia: answers serve to all teachers as an indication for improving the lessons.

Mgr Kasia Wyborska (teacher, and expert UMK) after four hours of teaching (12th Nov. 2019) writes:

Evaluation results based on completed questionnaires by pupils.

The form of conducting classes turned out to be very interesting for students. Experiences with electricity and a vacuum pump turned out to be the most interesting. The experience (electrostatic machine, plasma ball), which showed that in everyday life you can meet with a much higher voltage than those in the electrical outlet turned out to be a big surprise.

Solar powered bug caused a lot of joy. The plasma ball experience was also interesting. The pupils saw that it is enough to bring the fluorescent lamp close to the switched on plasma lamp to observe that its glow.

Another very interesting experience was with the vacuum pump. Students were surprised that in a short time it was possible to pump out air and create a vacuum. Thanks to this experience they understood what would happen if there was a vacuum around us.

From pupils responses, it is still necessary to conduct experiments in the context of electricity.

Pupils want to know more about current, when electricity is safe and when it is a major threat. The difficulty for students was to understand why a thousand volts generated by plasma lamp can be safer than 230 V in an electrical outlet.

Test of knowledge – 7th and 8th class of elementary school in Dąbrowa Biskupia (Poland)

The goal of the test was to check the knowledge of student attending FCHgo lessons on energy and electricity. As reported by Mgr Kasia Wyborska:

The aim of tests was to check the knowledge on the quality of air, renewable sources of energy and the knowledge on hydrogen.

Results of tests allowed to plan better the educational activity, adapt teaching contents to pupils' capacities and choose the most efficient methods of work with the students.

31 students answered 12 questions.

Result of test:

First three questions aim to check the knowledge on the quality of air. For 94% of students the quality of air is a **very big** or **big** problem. As the source of air pollution they listed: smog, smoke, burning coal, automobile transportation, acid rains. 60% of responding students think that the ban on burning xxx trash will improve the quality of our air. Others hope in the use of renewable sources of energy and in the public transportation.

Next four questions regarded the evaluation of the knowledge on renewable sources of energy (RSE). About 35% of pupils managed to indicate correctly the types of energy that we consider renewable. Three pupils did not know the acronym RSE and have not given any answer. Questions about solar energy and implementations of photovoltaic cells were answered correctly by 40% of students. This group knows what kind of *energy transformations* undergo in photovoltaic cell and which are the advantages. [M. Deichmann's video "Perpetuum mobile" was used by the teacher in her preparative phase]

On the questions related to the solar energy and the applications of the photovoltaic panels, correct answers were given by 39% of pupils. This group knows what kind of changes undergo in the photovoltaic panel and which are the advantages. On the question about the applications of solar panels pupils gave the most frequently following answers: *calculator, road signs, street lamps, portable radios, and the home use of solar energy.*

Last questions were in subject of hydrogen, its properties and applications.

Students have basic only knowledge on hydrogen. They know its chemical symbol and are able to show its position in the periodic table. They list the basic physical properties, i.e. the colour and the physical phase. On the question of ignition of hydrogen only half of students answered. The question – how hydrogen may be used – 100% student gave no answer.

Conclusions and observations:

Results of the inquiry show that not all pupils know what are the reasons and problems with the air pollution. A major part is not able to define the renewable sources of energy and to list correctly their sources. Questions about the use of hydrogen turned out the most difficult to the pupils.

It turns necessary to enrich the knowledge of pupils about renewable sources of energy, hydrogen cells, and explain the need for its production. With these activities we can rise not only the ecological knowledge of pupils but also increase their competence in the subject of new technologies, which are the future of our planet.

EVALUATION FORM FOR EXPERTS – SINGLE LESSON (Primary school, Poland)

Expert____Katarzyna Wyborska____

School________Primary School in Dąbrowa Biskupia_______________________

Class____6th grade primary school____

Lesson____What is electricity?____

Date____November 18, 2019____________________________________

Correspondence between the planned activity and the activity performed

Have the activities in class been performed according to the plan?

Lesson has been performed according to the FCHgo plan.

Contents of the meeting

Contents planned	Contents effective/ variations
Introduction to the topic.	
Discussion of different sources of electric voltage. (didactic show)	Electrostatic machine, Volta cell, galvanic cells,
Construction of a simple electrical circuit, according to the given scheme.	Work in groups under the supervision of a teacher,
Voltage and intensity measurements.	Work in groups under the supervision of a teacher,
Discussing the instructions for making an educational game based on the principle of operation of an electrical circuit.	Making of the scheme and game plan by pupils, create,
Summary and end of the lesson.	Completing the survey.

Methodological aspects

Have the following methodological aspects been adequate?
- time of the activities performed - one lesson unit (45 minutes),
- materials: electric wires, light bulb, battery, electric meters, electrostatic machine,
- the method of work: group work, didactic show, talk with students, take measurements, build circuits.

Evaluation: Lesson was assessed as interesting. During the lesson there was a constant arousing of students' curiosity by asking questions and using appropriate teaching aids. The students were very involved and took accurate measurements. After the lesson, the students made didactic games using the knowledge from the lesson.

In May 2020, during the prolonged lockdown of the schools, we have developed on-line instruments to assess the didactical outcome of FCHgo lessons done. This assessment is based in the same list of 13 questions on environment and hydrogen as used in the in-class tests in Dąbrowa Biskupia. Questionnaires were posed on Google and accessed by 81 pupils “trained” in FCHgo lessons and 24 pupils who accessed the test on the voluntary basis. Results are shown in Fig. 19.

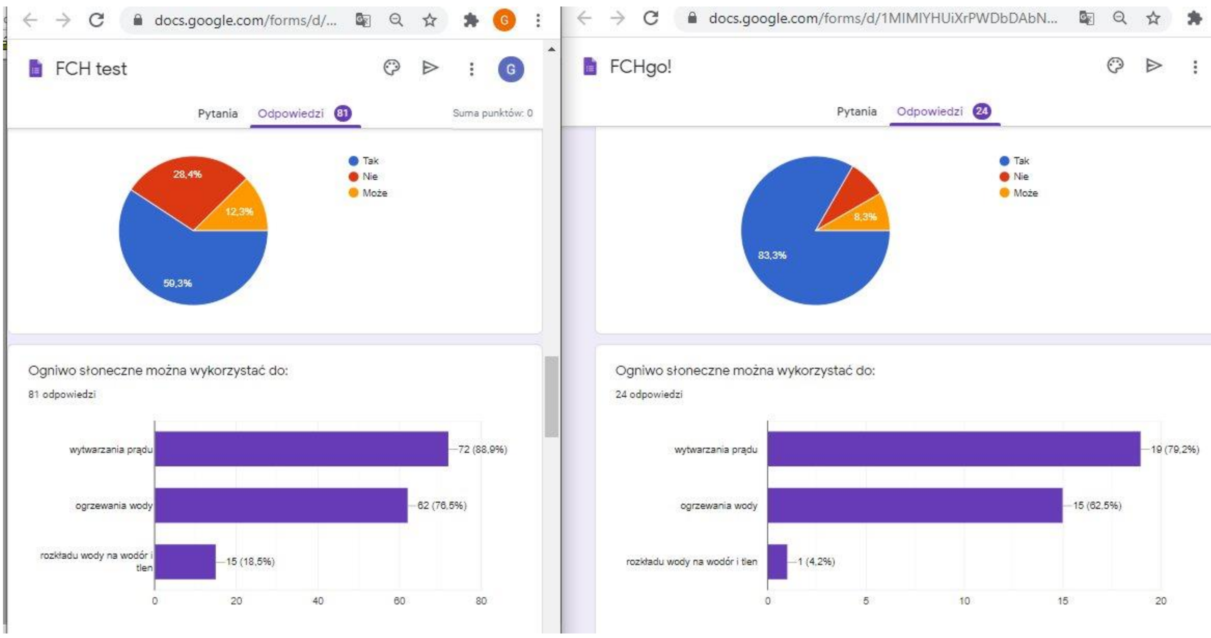

Fig. 19 - On-line tests of the didactical outcome of FCHgo lessons in Poland: pupils “trained” from Dąbrowa Biskupia and Ośniszczewko (81 persons, left panel) are compared with 24 pupils who accessed the site on the voluntary basis (right panel). Two chosen questions are shown. The pie graph answers to the question “Is hydrogen a renewable source of energy?”: blue – yes, red – no, yellow – maybe. The bar graph shows answers to the question “For what purposes a photovoltaic cell can be used?”: upper bar – to produce electricity, the middle – to heat water, lower bar – to make electrolysis of water into hydrogen and oxygen. Essentially, only pupils “trained” in FCHgo recognize the link between PV cell and hydrogen (in the control group, right panel only one person gave this answer). Author of the test and internet interface – Mgr Kasia Wyborska, May 2020.

EVALUATION FORM FOR EXPERTS – SINGLE LESSON (Secondary school, Poland)

Expert_____Anna Kamińska____

School_________ZSE Gdańsk____

Class__________I ____

Lesson______Climate changes ____

Date_______19.11.2019 ____

Correspondence between the planned activity and the activity performed

Have the activities in class been performed according to the plan?

Contents of the meeting

Contents planned	Contents effective/ variations
Climate change	Completed
The effects of climate change on humans and the biosphere	Completed
Energy resources	Completed

Methodological aspects

Have the following methodological aspects been adequate?
- time of the activities performed - good
- materials – good
- the method of work - good

Social “resonance”

FCHgo activities (and the very participation in the Project, as already stated) were appreciated by schools. Some teachers reported to us Internet sites that schools spontaneously created after FCHgo lessons. Two examples, from Gdynia and Gdańsk activities in November 2019 are given below (Figs. 20, 21). Material supplied by Mgr Tadeusz Bury.

Fig. 20 - The internet “reportage” prepared by secondary Technical school in Gdańsk, Poland, after the first of two series 2 x 2h lessons on climate, energy and hydrogen. Teachers were Tadeusz Bury and Anna Kamińska, November 2019.

Fig. 21 - The internet “reportage” prepared by Liceym in Gdynia, Poland, after the first of two series 2x 2h lessons on climate, energy and hydrogen. Teachers were Tadeusz Bury, G. Karwasz and Anna Kamińska, November 2019.

Pedagogical and experimental aspects

Here below we discuss in detail some of the aspects that were risen by the Project referees, in the report issued on May 12th, 2020: pedagogical, scientific, didactical, experimental, geographical and referring explicitly to hydrogen technologies.

As observed in the first run of FCHgo activity in schools, our approach differs significantly from traditional methods of teaching. This novelty is as such independently from the country, the geographical distribution of schools, the age of students and detailed contents of lessons. A common "denominator" of our approach is the narrative, interactive, and experimental character of teaching. Our action has identified three needs of teachers, by choosing: i) the pedagogy that they wanted, ii) the scientific contents that lack in school curricula, iii) a capillary, geographically diversified outreach.

(i) As discussed above, first of all in elementary schools, both pupils and teachers await alternative ways of teaching, resembling Steiner's (and Comenius's) "playing", instead of petrified school programmes. When working on new teaching concepts, we kept in mind the OECD Rapport on pedagogy [1] stating that in countries like Italy (and Poland, see the graph below, Fig. 22), teachers were aware that the official school curricula were much traditional and would desire to introduce constructivistic ways of teaching. As seen below, Italy teachers admitted the most traditional teaching out of twenty-three OECD countries compared; Polish teachers *believe* in constructivistic teaching, but in practice they lack means and contents of such didactics.

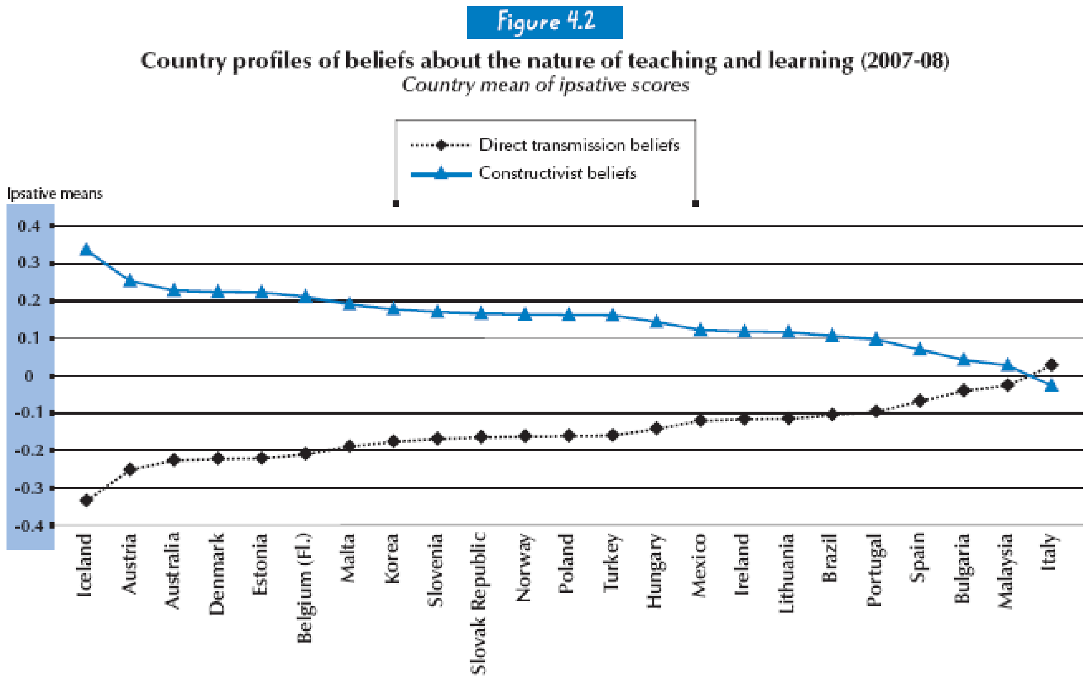

Fig. 22 - Attitudes *vs* traditional and constructivistic teaching in selected OECD countries.

[1] Creating Effective Teaching and Learning Environments, First Results from TALIS, OECD, 2009, p. 95. https://www.oecd.org/education/school/43023606.pdf (accessed 15/06/2020)

(ii) Textbooks books introduce „forces" of nature already in early teaching (Fig. 23 - for 2nd class of Italian primary school), compared with "Apple Story" illustration. In Poland, as results from the feedback after FCHgo testing, pupils at villages are aware that “burning rubbish is harmful” – they feel it breathing outside. But they never realized, that apple is “made of” water and sun, with some admixture of carbon dioxide, as we say it indirectly in the “Apple story”.

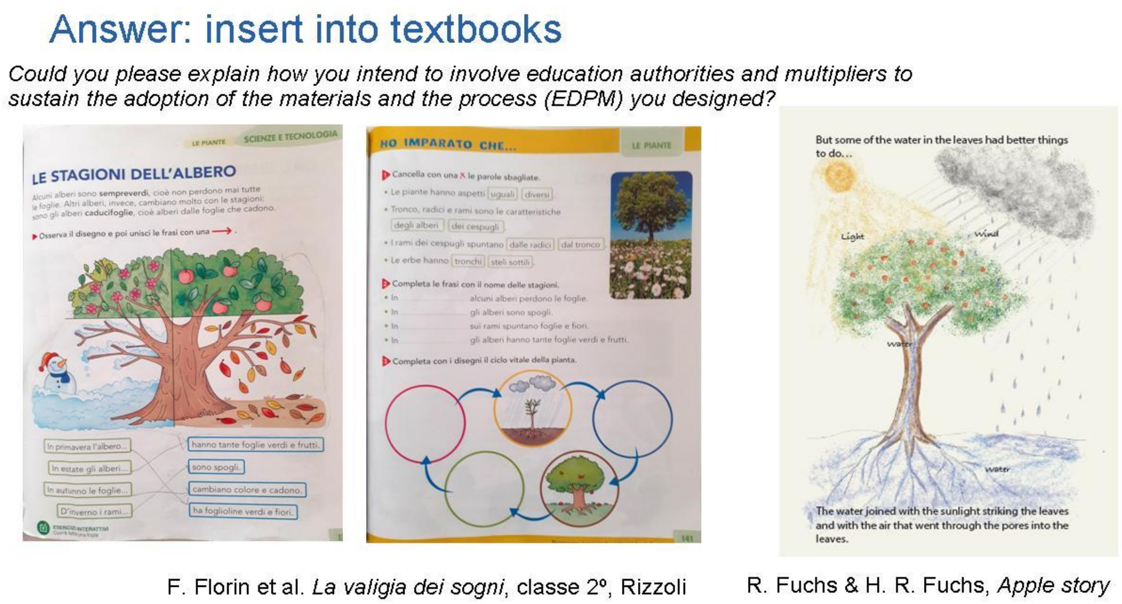

Fig. 23 - Towards inserting contents of FCHgo to traditional school textbooks. Italian primary school; collage by G. Karwasz.

(iii) The list of experiments, like suggested by the referee, is under intense preparation and testing. We started, in September 2019, i.e. before first test in schools, with a very broad “Thesaurus” of experiments on the energy conservation and preparation, that is based on simple (and cheap) objects that teachers can use also in other activities, comprised advanced lesson in physics (see fig. 24). Obviously, the relation to hydrogen technologies was only vague: to be tested and choose the most appropriate for teaching on hydrogen.

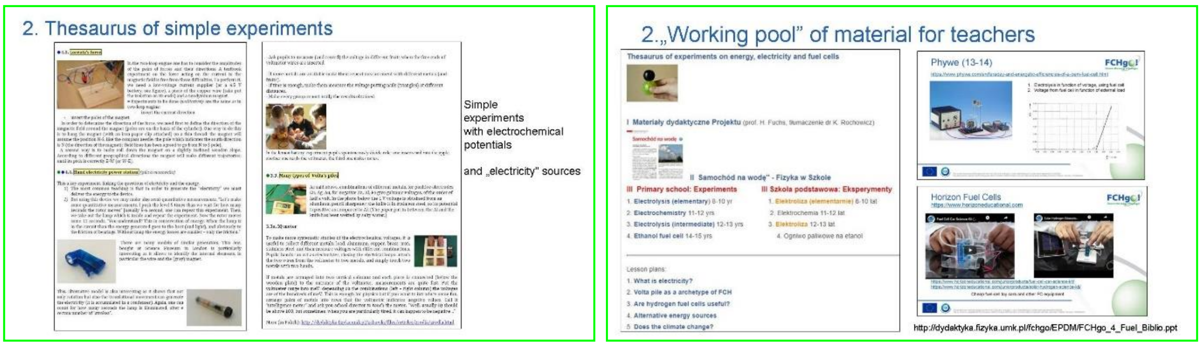

Fig. 24 - Two snapshots from “work-in-progress” pages for teachers. UMK, Toruń, Didactics of Physics Division, http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/857 (accessed 15/06/2020).

As an intermediate step we prepared “a pool” of experiments on energy transformations and hydrogen technologies (see fig. 25). The motivation was that “professional” experiments with fuel cells are expensive (>500 USD), the cells are far from being technically perfect (and can be easily damaged) and the budget of the Project does not allow to buy the equipment for all schools involved. As stated by one of German teachers, even simple "hand" dynamo torch is not available to many elementary schools.

Fig. 25 - The second stage of preparing "recommended" experiments in FCHgo: description of more complex experiments on fuel cells, electrolysis, photovoltaics.

Some cheaper equipment was bought by UMK already in April 2019 (toy cars, but with separated PV cell and fuel cell, so not showing didactically the full renewable energy cycle) and discussed with partners at the GIREP congress in July 2019. Mainly due to budget limits, only in March 2020 we bought the advance kit (one set): experiments will be filmed, commented, and "recommended", if school partners want to buy them.

The experimental kits were appreciated in all schools, see the photo report from activities in Germany: https://fchgo.eu/news/fchgo-lessons-in-german-schools-pupils-are-fascinated-by-fuel-cell-model-car/

The list of experiments to be recommended will be issued when all teachers involved in the first stage of testing express their preferences. Due to a high load of work for teachers in Spring 2020, we can ask them to do it only in July-August 2020.

(iv) The choice of the geographical distribution of school testing proved to be very successful. We found very different approach and perception in big cities (Winterthur, Bolzano, Gdańsk, Gniezno, Słupsk, Gdynia) and small towns/ villages (Formigine, Dąbrowa, Strzelno, Brusy, Kowalewo etc.). In big cities the FCHgo lessons were just added to rich extra-scholar activities (visits of experts, workshops at the university, educational travels etc.). Therefore, it was quite difficult to attract the attention of students, in particular in secondary schools. Narrative scenarios of Power Point lessons combined with interactive experiments proved to be successful in this goal.

Differently, in small schools the visit of FCHgo experts was a non-expected event, a kind of *fiesta*. Children expressed all their originality in reporting the contents and parallel, own ideas, see example on the figure 26.

Energy & apple for lower primary: Ośniszczewko

The methodology: Apple story + play cards + experiments on alternative energies

Activities in 2nd class (7 yrs old) in primary schools in Ośniszczewko (Feb. 2020). Teacher: Kasia Wyborska.

Fig. 26 - „Draw what you have learned during the FCHgo lesson“ – a task for 7-yrs old children in small village (the total number of students in the school 60) in Poland. Children have very original ideas on what energy, environment and hydrogen technologies are. © Kasia Wyborska & FCHgo consortium.

Concluding: the first series of school activities, even if not concluded according to the plan from May 2019, gave already important indications for the efficiency of both new pedagogy and for interest in hydrogen technologies. The educational material, even if with similar contents, can explore different students' abilities, according to their age, geographical place and their already acquired knowledge.

Next actions

A complete evaluation of the educational activities in schools was supposed to be done in May 2020. The COVID-19 situation changed these plans: an extension of the Project is needed to finalize the evaluation of the didactical outcome. In any case, we can predict the need for some international "refinements". The activities, although based on a common pool of material, differed in the five countries involved, for reasons discussed above. A refinement of evaluation will be needed applying common forms, intermediated between different national applications. We have already undertaken such intermediations:

1) "Energy box" from University of Bolzano (Prof. Federico Corni and collaborators) was brought to Poland and distributed to two groups working with early-scholar teaching: mgr K. Wyborska, UMK expert and teacher, and mgr Grzegorz Wojewoda, teacher adviser for Pomeranian Regions, in charge of preparing physics teachers for early years of elementary school. This box has been duplicated, by buying a similar equipment by UMK. As a result, narrative teaching for the age 8-10 is under wider implementation in Poland.

2) Some equipment for experiments has been forwarded from UMK to UNIMORE: after the initial trial, a refined set of experiments will be prepared in common.

3) Prof. Grzegorz Karwasz participated in lessons for secondary school teachers at Free University of Bolzano, in October 2019 and as outcome 5 video lessons in Italian have been registered. Lessons in Polish are under registration. Additional, remote activities have been done in the period March- May 2020: a remote participation in the biggest science divulgation event in Poland, "Science Picnic" in Warsaw, one local (Toruń) TV interview and one radio broadcast on new technologies (Toruń).

4) Prof. Anke Hagen supplied her educational material for secondary schools: a part of this will be incorporated into next series of video lessons for Polish teachers. Variations of the didactical outcome tests, more related to hydrogen and somewhat different for different countries are under preparation.

In the new work plan the period from September 2020 till December 2020 will be devoted to new runs of teaching, in parallel with the evaluation of the didactical outcome.

Deviations

No major deviations from the plan of activity as defined in May 2019 appeared before the Coronavirus pandemic.

Minor deviations are related to two factors. First, the diversity of educational systems and background (and running reforms) caused the necessity to diversify the contents and forms of the educational material. These enriched forms multiplied the amount of the materials (we developed films, YouTube lessons and “thesaurus” of experiments), but elongated the preparation phases. So, the training materials for teachers and educators were still under development in October 2019, when the starting of lessons in schools was planned in all countries. Nevertheless, as described, in some countries the pilot lessons were performed, even if the preparation of teachers was still running.

The first version of this deliverable was concluded in date January 15th 2020 (and submitted in date 31/01/2020). The expected line of events was to conclude the first series of lessons by March. However, in date February 23nd closing of schools in Lombardy and Emilia-Romagna (Italy) was announced, and the sequence of events from then is well known. This had a huge impact on the possibility to complete all educational activities. In order to cope with this, in February and March 2020 additional material was delivered on-line (and re-organized on the internet sites). This allowed to continue some remote activities with children (they prepared drawing, wrote stories etc., enriching in this way the evaluation of the didactical efficiency of FCHgo, see for ex. https://fchgo.eu/news/small-batteries-big-fun-a-fchgo-lesson-in-poland/.

However, thanks to the extension of the project, a new schedule is in place in order to complete all educational activities. The new deadline will be at the end of December 2020.

Finally note, that the pandemic in Spring 2020 was the only event not predicted by the Project: “the system of early monitoring of epidemic” was one of 5 priorities of European Research Council in 2013-2016 [2]

[2] Labareda, J. (2019) *Open Europe. Policies, reforms and achievements in EU science and innovation 2014-2019 under EU Commissioner Carlos Moedas : open innovation, open science, open to the world*, Bruxelles: EU Commission, Directorate-General for Research and Innovation.

https://op.europa.eu/en/publication-detail/-/publication/0dc27be9-de75-11e9-9c4e-01aa75ed71a1

Main Conclusions

The first stage of didactical activities in 5 countries started from October 2019. Due to national preferences and/or differences in the social educational needs, the activity was projected to be spanned over the period ending in March 2020.

We need to add again that, due to *force majeure,* the planned development of the Project was interrupted. New sequences of activities in schools, to some extent *ex nuovo* (due to new pupils entering the FCHgo cycle in September) are under preparation and are expected to be concluded by the end of 2020. Similarly, the study of the educational impact will be modified.

The first results have been encouraging: students follow lessons with interest and teachers are happy with the contribution brought by FCHgo experts in different fields, according to the division of tasks:

- narrative physics in the subject of energy
- environmental sensitivity
- technological aspects of alternative energies and hydrogen fuel cells.

It is important to note that the rough evaluation of the totality of students involved is very promising: at present about **1300 students are involved** in FCHgo activities, as compared to **900 expected** in the phase of Project planning.

Concluding: in spite of the broken path of planned lessons in schools, the activities performed in the first year of the Project allows to draw conclusions for changes in the educational material. The gained evidence of broad interest should also allow further divulgation of teaching on hydrogen technologies.

Appendix I

EVALUATION FORM FOR EXPERTS – SINGLE LESSON

(Prepared by UNIMORE & UNIBZ team, Dec. 2019.)

This form should be completed by expert for every lesson

Expert____

School____

Class____

Lesson____

Date____

Correspondence between the planned activity and the activity performed

Has the activities in class been performed according to the plan?

Contents of the meeting

Contents planned	Contents effective/ variations

Methodological aspects

Has the following methodological aspects been adequate?

- time of the activities performed

- materials

- the method of work

- …

EVALUATION FORM FOR EXPERTS – the entire course

This form is to be completed by the expert at the end of the whole course in a given class.

Expert____

School____

Class____

Variations and adaptations as compared to the plan

Indicate possible variations in the lesson plan and in the activities proposed (and the motivations for the variations).

Appendix II: example of teacher's questionnaire

1. EVALUATION FORM FOR EXPERTS – complete educational process

This form must be filled in by the experts at the end of the entire educational process in each class.

Expert Ulrike Krämer

School GS Haag-Wolkar

Class 4

Evaluation of the activities

Regarding **the interest and involvement of students in scientific disciplines**, please indicate the usefulness of each activity on a scale of 1 to 5 (1: little useful; 5: very useful).

1. Meeting 1	
1. “Apple story” reading	2
2. Analysis of verbal and non verbal language	2
3. Explanation of the “Toy Guide”	2
Between Meeting 1 and Meeting 2	
1. Exploration of the Toys	1
2. Finishing the analysis of the language of the “Apple story”	2
Meeting 2	
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	3
2. Introduction of carriers	2
3. Card Games: “Find the exchanger” and “Find the Carrier”	2
Between Meeting 2 and Meeting 3	
1. Exploration of other Toys brought by pupils	1
2. Watch the movie “Perpetuum mobile”	1
3. Write “Stories of the Dynamics” of different toys	-
Meeting 3	
1. Planning and writing of the storyboard of Role playing	3
2. First rehearsals of the Role playing	3
Between Meeting 3 and Meeting 4	
1. Performing of the Role playing	3
2. Filming the Role playing	3
Meeting 4: fuel cell car	
1. Comparing stories of the dynamics of a toy (“Rechargeable flashlight” and “Fuel cell car”)	3
2. Drawing the *Energy Diagrams* for both toys	-
3. Evidence the analogies between the two toys (“Rechargeable flashlight” and “Fuel cell car”)	-
(for older pupils)	
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	-
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	-

Evaluation of the activities

Regarding **the knowledge and understanding of the contents**, please indicate the usefulness of each activity on a scale of 1 to 5 (1: little useful; 5: very useful).

1. Meeting 1	
1. "Apple story" reading	3
2. Analysis of verbal and non verbal language	3
3. Explanation of the "Toy Guide"	3
Between Meeting 1 and Meeting 2	
1. Exploration of the Toys	2
2. Finishing the analysis of the language of the "Apple story"	2
1. Meeting 2	
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	2
2. Introduction of carriers	2
3. Card Games: "Find the exchanger" and "Find the Carrier"	2
Between Meeting 2 and Meeting 3	
1. Exploration of other Toys brought by pupils	1
2. Watch the movie "Perpetuum mobile"	1
3. Write "Stories of the Dynamics" of different toys	-
Meeting 3	
1. Planning and writing of the storyboard of Role playing	3
2. First rehearsals of the Role playing	3
Between Meeting 3 and Meeting 4	
1. Performing of the Role playing	3
2. Filming the Role playing	5
Meeting 4: fuel cell car	
1. Comparing stories of the dynamics of a toy ("Rechargeable flashlight" and "Fuel cell car")	3
2. Drawing the *Energy Diagrams* for both toys	-
3. Evidence the analogies between the two toys ("Rechargeable flashlight" and "Fuel cell car")	-
(for older pupils)	
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	-
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	-

Evaluation of the activities

Regarding **the use of scientific thinking based on analogies and metaphors**, please indicate the usefulness of each activity on a scale of 1 to 5 (1: little useful; 5: very useful).

1. Meeting 1	
1. "Apple story" reading	3
2. Analysis of verbal and non verbal language	3
3. Explanation of the "Toy Guide"	3
Between Meeting 1 and Meeting 2	
1. Exploration of the Toys	2
2. Finishing the analysis of the language of the "Apple story"	2
Meeting 2	
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	3
2. Introduction of carriers	3
3. Card Games: "Find the exchanger" and "Find the Carrier"	3
Between Meeting 2 and Meeting 3	
1. Exploration of other Toys brought by pupils	3
2. Watch the movie "Perpetuum mobile"	3
3. Write "Stories of the Dynamics" of different toys	-
Meeting 3	
1. Planning and writing of the storyboard of Role playing	3
2. First rehearsals of the Role playing	3
Between Meeting 3 and Meeting 4	
1. Performing of the Role playing	3
2. Filming the Role playing	3
Meeting 4: fuel cell car	
1. Comparing stories of the dynamics of a toy ("Rechargeable flashlight" and "Fuel cell car")	-
2. Drawing the *Energy Diagrams* for both toys	-
3. Evidence the analogies between the two toys ("Rechargeable flashlight" and "Fuel cell car")	-
(for older pupils)	
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	-
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	-

Evaluation of the activities

Regarding **the ability of discussion and collaboration among students**, please indicate the usefulness of each activity on a scale of 1 to 5 (1: little useful; 5: very useful).

1. Meeting 1	
1. "Apple story" reading	1
2. Analysis of verbal and non verbal language	2
3. Explanation of the "Toy Guide"	2
Between Meeting 1 and Meeting 2	
1. Exploration of the Toys	1
2. Finishing the analysis of the language of the "Apple story"	1
Meeting 2	
1. Reviewing and sharing of the *Toy Guides* filled in by the pupils	2
2. Introduction of carriers	2
3. Card Games: "Find the exchanger" and "Find the Carrier"	2
Between Meeting 2 and Meeting 3	
1. Exploration of other Toys brought by pupils	1
2. Watch the movie "Perpetuum mobile"	1
3. Write "Stories of the Dynamics" of different toys	-
Meeting 3	
1. Planning and writing of the storyboard of Role playing	3
2. First rehearsals of the Role playing	3
Between Meeting 3 and Meeting 4	
1. Performing of the Role playing	2
2. Filming the Role playing	3
Meeting 4: fuel cell car	
1. Comparing stories of the dynamics of a toy ("Rechargeable flashlight" and "Fuel cell car")	-
2. Drawing the *Energy Diagrams* for both toys	-
3. Evidence the analogies between the two toys ("Rechargeable flashlight" and "Fuel cell car")	-
(for older pupils)	
1. *Other analogies and comparisons: with or without accumulation, electricity as an input or output, reversibility or less of the exchangers, …*	-
2. *Reasoning on hydrogen technologies, advantages of hydrogen*	-

Evaluation of complete educational process

- In general, how do you rate the entire educational process?
- Which critical elements need to be addressed?
- State your opinion about the disciplinary contents
- State your opinion about the methodological contents

Other thoughts?

Appendix III

Evaluation questions for secondary schools (15-18 yrs old)

FCHgo – competence tests (G. Karwasz, Oct. 2019):

a pool of questions on energy, environment, hydrogen to be chosen by the teacher.

What is the energy? Choose the best answer.

1. A feature that every physical object possesses.
2. A feature that physics objects can interchange
3. A feature that allows the world to turn.
4. A feature that should be preserved and saved.

Which sentence is *incorrect*?

1. The mechanical energy can be converted into the heat.
2. The heat can be converted into the mechanical energy.
3. In "energy transformations" there are always some losses.
4. The efficiency

Which of these physical phenomena is not used as the energy carrier?

1. The electrical current
2. Solar light
3. Running water streams
4. Compressed air

In which of these experiments there will be *no electrical current* created?

1. Moving closer the spheres carrying electrical charges
2. Moving a magnet through a wire loop
3. Supplying hydrogen and oxygen to two separate electrodes
4. Placing different metals into a pile in which the every second pair is separated by a piece humid paper.

Choose the correct sentence

1. In energy transformations a given carrier can bring only one form of the energy, like water bringing its kinetic energy.
2. In energy transformations the sum of all energy forms (including the heat) gradually diminishes.
3. The Universe, as a whole, conserves the sum of all forms energies, keeping in mind $E=mc^2$.
4. Silicon photovoltaic panels are cheap in production.

Which sentence is correct?

5. The climate on Earth is becoming warmer because of the changes in the energy emitted by Sun.
6. The main greenhouse gas on Earth is CO_2.
7. The level of CO_2 in last 400,000 years was constant.
8. The atmosphere is transparent for the infrared light.

What is the main advantage of using hydrogen in fuel cells? Choose the best answer.

5. Hydrogen is cheap to be produced.
6. Burning hydrogen does not emit CO_2.
7. Efficiency of fuel cells is, potentially, higher that burning hydrogen in combustion engines.
8. Fuel cells are simpler in construction than combustion engines.

Which statement is the most appropriate?

5. We develop alternative energy “sources” because they are cheaper than oil or coal.
6. We develop alternative energy “sources” because they emit less pollutants than burning coal or petrol
7. We develop alternative energy “sources” because there is no other choice: available currently technologies of energy “production” soon will be not sufficient for the humanity as a whole
8. We develop alternative energy “sources” because they do not disturb the landscape.

Which statement is correct?

1. The efficiency of silicon photovoltaic panels is surely above 20%.
2. There are not losses for the heat in hydrogen fuel cells.
3. The geothermic energy is sufficient for the whole humanity, but we must learn how to use it.
4. The voltage from hydrogen fuel cells is slightly lower than the voltage needed for the electrolysis of H_2O.

Which of these phenomena do not occur in hydrogen fuel cells?

1. Converting the chemical potential into electrical potential
2. Migration of free electrons through a polymeric membrane
3. Creation of the heat inside the cell
4. Solving of the gaseous hydrogen and oxygen in water

Why the hydrogen-driven cars are not used yet on large scale? Choose the best answer

1. No car company invested enough into the research
2. Hydrogen is much more dangerous in case of fire than benzin.
3. Catalyst used in hydrogen cell are poisonous.
4. The most important components of the hydrogen fuel cells, i.e. catalysts and the proton-conducting membrane are still expensive.

Appendix IV

Evaluation for the first series (2h expert + 2 h teacher) of FCHgo lesson in primary school (7th-8th form, 13-14 yrs old) in Poland (prepared by mgr Kasia Wyborska)

The evaluation survey is an anonymous class ....
Finish the sentences.
1. The lesson was ....
2. What I liked most about this lesson was ....
3. In the lesson I found out ....
4. After this lesson, I understand better ....
5. During the lesson, I was surprised ....
6. It was difficult for me ....
7. I would like to know more about ....
8. Would you like more such lessons? ....
Other remarks and observations ....

Thank you