FUEL CELLS HYDROGEN EDUCATIVE MODEL GOES TO SCHOOLS – FIRST RESULTS ARE ENCOURAGING

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Abstract

Hydrogen fuel cells have been invented almost two hundred years, but their practical applications are still at the level of prototypes. Nowadays, growing environment problems urge to find new technical solutions. At the same time, the social awareness must increase. "Fuel Cell Hydrogen Educational Model Goes to Schools" is the research project within Horizon2020 Framework, Fuel Cells and Hydrogen 2 Joint Undertaking. The research group comprises Italy, Switzerland, Germany, Denmark and Poland. The aim is to elaborate the didactical models in the subjects of the environment, energy and hydrogen technologies, suitable for pupils aged 8-18 years, all across Europe. The variety of the material elaborated proves to be "appetizing" both for teachers and pupils: the Project acts towards the breakthrough of the mentality on the use of hydrogen cell technologies.

Key words

environment, energy, hydrogen fuel cells, educational model

Introduction

Weather (and football) are subjects where more specialists exists than citizens. The social awareness concerning climate changes ranges from complaints about scientists "that do not understand simple things that my grandmother already knew" to worldwide strikes of young people against global warming. The EU funded "Fuel Cell Hydrogen Educational Model Goes to Schools" (FCHgo) Project was created to move past these two extremes: it is meant to demonstrate the necessity and technical solutions for not only mitigating climate change~~s~~ and local urban pollution~~s~~, but for changing our way of thinking at the very basic level, starting from early primary school.

The difference between this and many other approaches to teaching about climate, regenerative energy, and hydrogen technologies is that we insist on *understanding* the concepts of energy conservation, energy carriers, and energy dissipation. We do this by using a *narrative* approach, via simple stories children can understand, that refer directly to nature (a story of an apple, an animated story of a perpetuum mobile, etc.), and interactive, simple experiments (Volta's batteries and hydrogen toy cars).

The project involves Italy, Germany, Switzerland, Denmark and Poland: in each country the social awareness and the technological needs are different, so have created targeted contents. In didactic experimentation to date, the involvement of teachers and the enthusiasm of pupils contributing with their drawings, stories, and spontaneous playing with experiments is strongly encouraging.

Here we describe FCHgo contents and methods, which are based on narrative principles – interactive discussing and common, with pupils, solving questions. We give first didactical results, both as introducing the novel methodology, as well - and even more decisive – in rising social awareness among youth people on the necessity of technological transformations in the field of energy "resources", their sustainability and environment cleanness.

New "sources" of energy for XXIst century

The European didactic project FCHgo! - Discover the energy of hydrogen brings energy issues into European classrooms by supporting hydrogen and fuel cell education in schools. The issue is extremely important from the technological and social point of view. The nineteenth century was the age of the steam engine, the twentieth century was the era of the domination of the internal combustion engine, while the twenty-first century will probably be the age of the fuel cell. FCHgo is a European project dedicated to fostering knowledge about fuel cell and hydrogen technology by delivering an educational model for schools.

The project invites pupils and their teachers alike to discover the energy of hydrogen with innovative teaching materials and along inspiring activities in classrooms and beyond. The aim of the Project is to raise public awareness through didactic and popularizing activities in the field of:

- climate change,
- alternative "sources" of energy,
- hydrogen technologies, in particular fuel cells.

The FCHgo project was supported by the European research and innovation program Horizon 2020 under the aegis of Fuel Cell and Hydrogen Joint Undertaking (FCH JU). A two-year project that started in January 2019 is coordinated by Università Modena Reggio Emilia in cooperation with InEuropa srl Italy, Zürcher Hochschule für angewandte Wissenschaften, Technical University of Denmark, Nicolaus Copernicus University and Steinbeis 2i GmbH. In the FCHgo project, scientists, experts and teachers in science education work together to inspire students and teachers to both use hydrogen and the importance of its potential role as an energy source. FCHgo project! brings energy into European classrooms by supporting hydrogen and fuel cell education in schools.

Hydrogen is the most abundant element in the Universe and is a clean energy carrier, but the possibility of using H_2 energy is a rarely discussed topic in school. Even simple experiments with hydrogen as a chemical element are rarely run in schools. To support energy education in schools, the EU FCHgo project proposes an innovative teaching concept, based on narration, and multimedia materials that inspire teachers, students and their parents to know about the world of hydrogen energy, or even more, quoting Jerome Riffkin – "Hydrogen economy".

The project is a practice-oriented set of educational exercises for interactive lessons on fuel cells and hydrogen. FCHgo develops a set of learning activities tailored to teach students aged 8 to 18. The kit includes games, stories, scenarios and experimental kits that visualize how energy processes work and inform students about the various uses of hydrogen. To ensure that the materials are well suited to educational practices and draw on the latest FCH research and industrial development, FCHgo partners will engage a wide range of stakeholders from education, science and industry. FCHgo project will contribute to the broadly understood science of energy by proposing a narrative and innovative approach to teaching FCH. The aim is not only to impart knowledge about fuel cells and hydrogen, but also to stimulate students' interest and open their minds to the world of science.

Narrative didactics on energy and hydrogen

Social awareness on environmental issues and the state of technological development of alternative energy “sources” differs much, say between Poland, with economy still based on carbon and Denmark, obtaining a quarter of the national electricity from wind. Therefore, we present a vast approach that include both on-line presentations and simple interactive experiments on energy, electricity, hydrogen and fuel cells.

The novel approach consists, from the formal point of view, in treating physical concepts like the energy, momentum, chemical potentials as flow diagrams. This kind of diagrams makes clear that the energy is not “produced” but changes forms: the left and right side of diagrams are always in parity. In fig. 1. we present such a diagram explaining formally the processes in hydrogen fuel cells. The diagram shows the flows – of the two “energy carriers” of the chemical type. i.e. hydrogen and oxygen on the left side and the electrical current produced on the right side. A missing part in the energy balance is the heat produced.

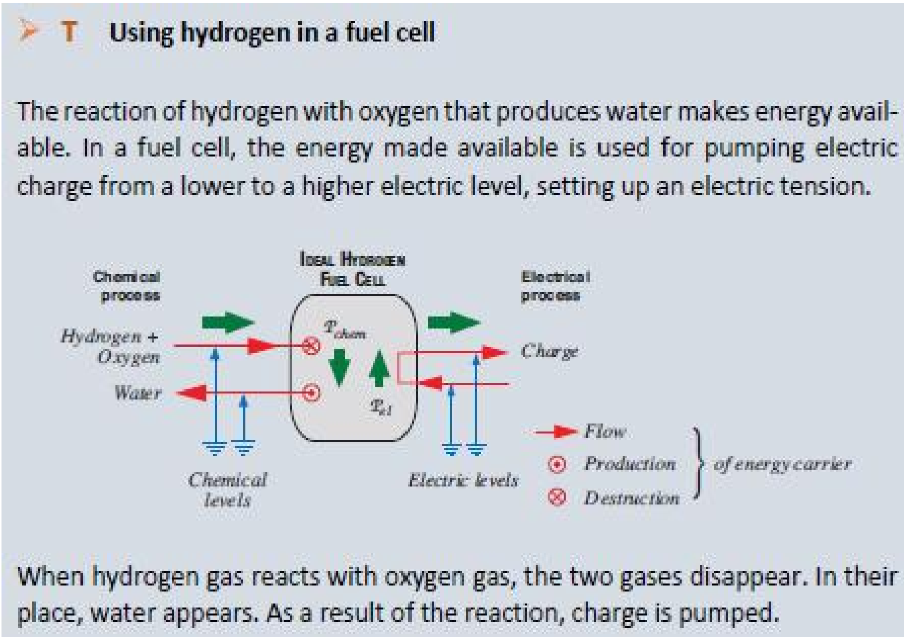
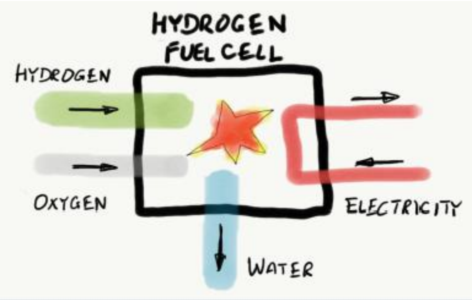


Fig. 1. The formalism explaining flows of the energy in a hydrogen fuel cell. From FCHgo didactical materials (Fuchs 2019, see www.fchgo.eu).

Obviously, a fully formal approach is too much difficult to be explained to young pupils. Therefore, and this is the main challenge of the FCHgo, both the Project university staffs and teachers are involved in “translating” the very formal concept that the energy is conserved and not “produced” into easy to understand and appealing to children imagination pictures, games, videos. An example is shown in fig. 2.



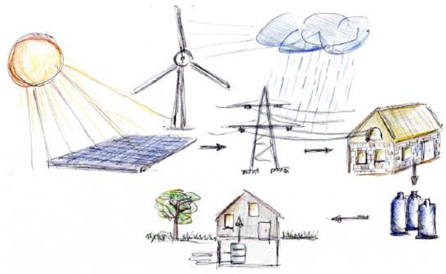


Fig. 2. Easy-to-understand pictures explaining concepts of energy transformation and "alternative" energies. From FCHgo material by H.U. Fuchs (2019), drawings by R. Fuchs.

First, it is important (for us, as physicists and biologists) to teach the laws of "conservation" – of the energy and matter: nothing appears from null and nothing disappears in null. We use notions of the energy carriers: their continuous flow is the essential notion. To explain it to children 8-10 years old, "An Apple Story" (Fuchs & Fuchs, 2019) has been prepared, see fig. 3. Not being able to use the term "energy forms" we speak about "forces" that contribute to an apple growing: sunlight (bringing the energy in the form of photons), water and "air" (in reality the CO_2) needed for the chemical transformation of hydrogen, carbon and oxygen into organic matter.

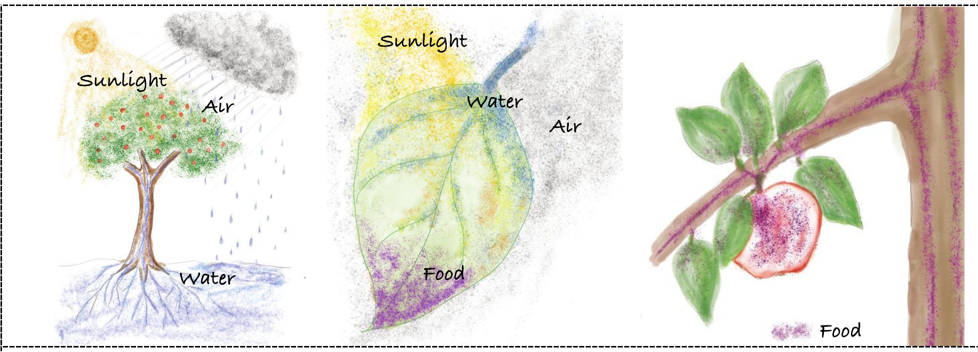


Fig. 3. Illustrations from *An Apple Story*. Left: A tree and three "forces", sunlight, water, and air. Center: The forces come together in a leaf where they will blend, fade away and create food. Right: The food travels to parts of the tree and into the growing apple. Selection from Dumont et al. (2019).

The narrative approach uses the resources of the common, informal language, to introduce the desired concepts of physics and chemistry. The knowledge is not given to students as ready notions but discussed together (Corni et al. 2019). An example of the metaphor and narrative approach on hydrogen technologies is shown in fig. 4.

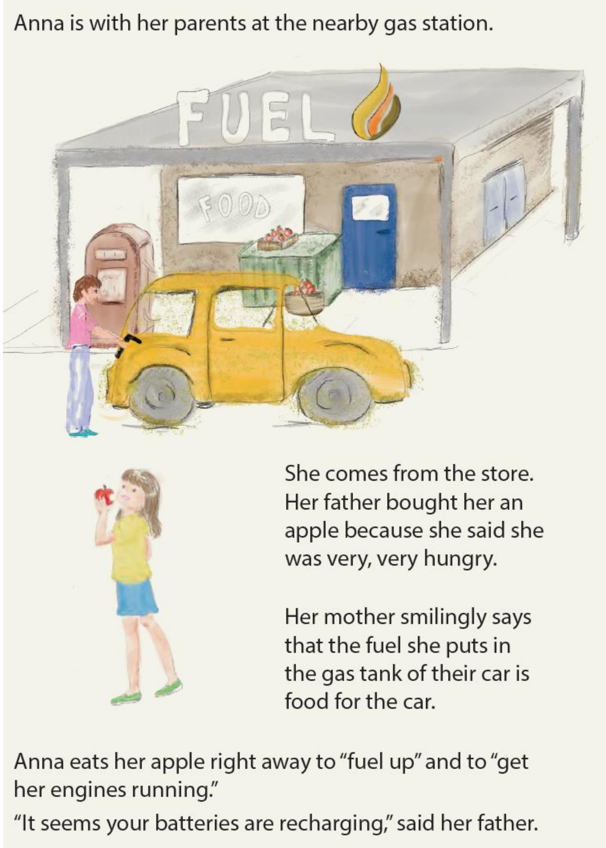


Fig. 4. The use of the common, informal language to explain the interdisciplinary concepts of energy transformation: from the chemical form (petrol, apple) into the kinetic energy and the heat (car) and all physiological activities (playing, speaking, reasoning) by Anna who eats the apple. The last sentence "the batteries are recharging" introduces indirectly the subjects of hydrogen fuel cells. Drawings by R. Fuchs, from "An Apple Story" (Fuchs & Fuchs, 2019).

Similarly easy-to-understand but surprising in concept is the video story on "Perpetuum machine" by Marion Deichmann [5], prepared under the scientific supervision by H. Fuchs. It starts from an old dream of endless chain of energy transformations, but expanded into modern forms: photons form a lamp, photovoltaic cells, electric dynamo. The story starts from the force of a hand which puts into motion the dynamo. Different carriers of energy are illustrated by colorful "ghosts" that sleep or move when they bring the energy flow. The conclusion from the video is that without an external source of energy the whole cycle is not possible. But when sun shines as such a source the whole cycle of energy transformation goes for ever (as long as sun illuminates the machine…)

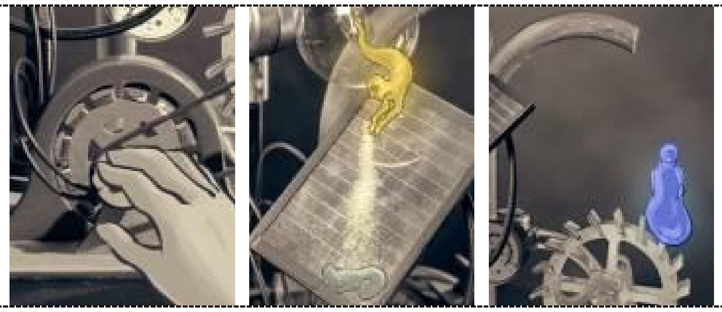


Fig. 5. Initially, the inventor drives the generator of the Perpetuum Mobile machine by hand. Light drives the solar cell, a pump pumps water high up whereupon it falls down. There are "ghosts" or "spirits" at work in the machine which play an important role later in the story told here. From Deichmann (2014).

To complete the set of the narrative material an energy card game has been prepared. Students exchange cards that illustrate different forms of energy – like in a physical process, see fig. 6.

Fig. 6. Cards representing forces of nature (as energy carriers) made available through Ergoland. Left: The card developed for hydrogen (like every card, it displays three possible levels, i.e. potentials). Middle: The card developed for heat. Right: The card developed for electricity.

Different elements – "Perpetuum mobile" video, the interactive experiments with electrolysis, diagrams of processes and elements of fuel cells are incorporated into teaching scenarios, see fig. 7. In schools that volunteered for testing a series of four meetings with experts, each meeting of two hours was proposed.

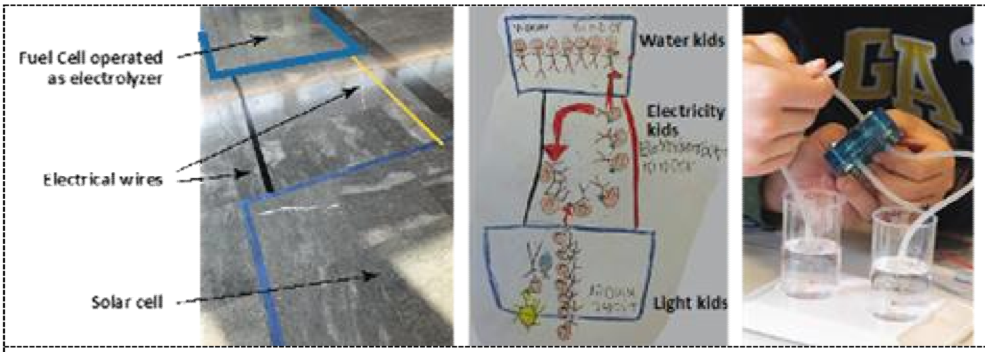
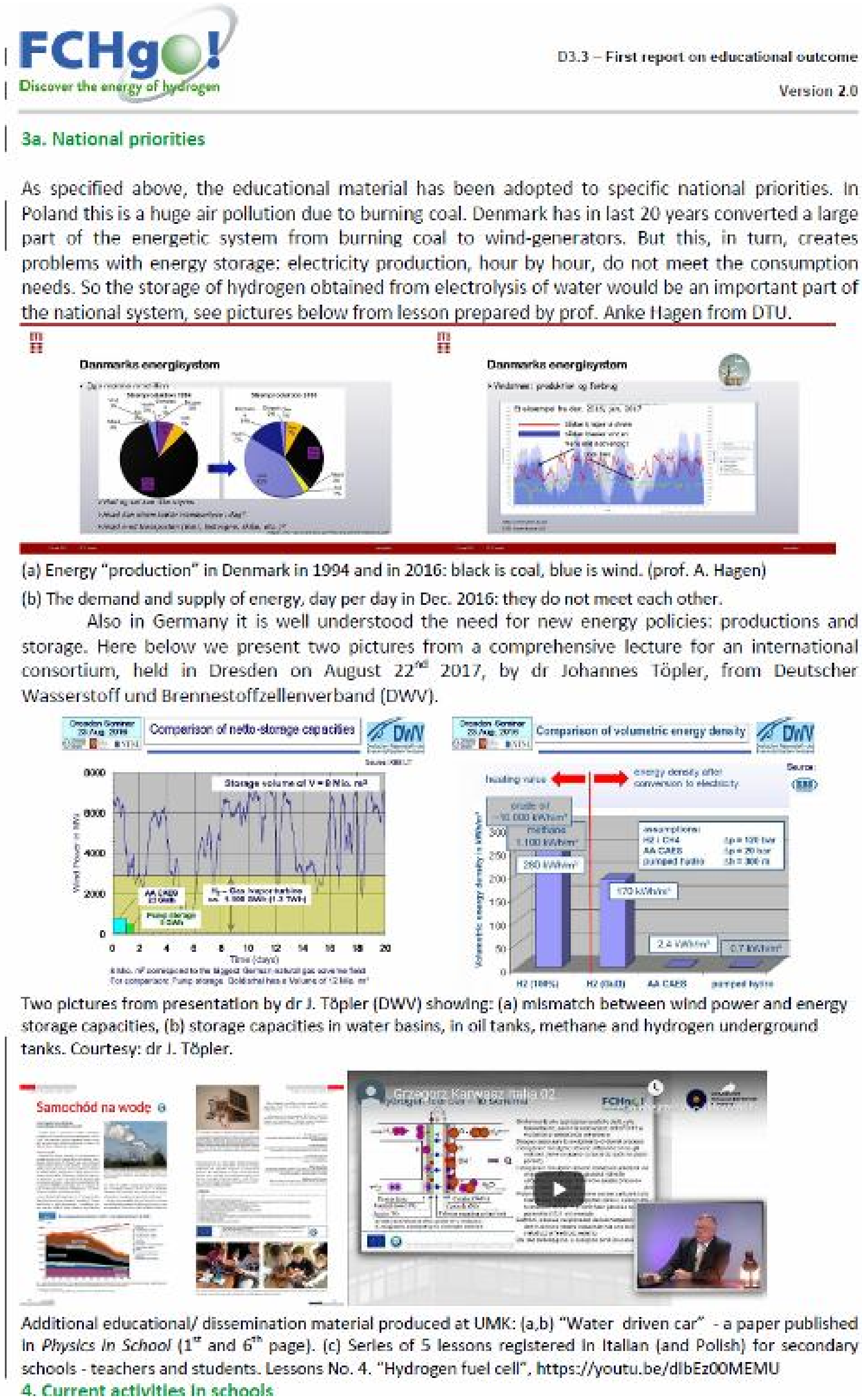


Fig. 7. A primary school class in Switzerland (2nd graders) play forces of nature acting and interacting in a lamp-PV-cell-electrolyzer system. Left: The floor with an outline of solar cell (bottom) and electrolyzer (top) with the paths (cables) for electricity between them. Center: A drawing by a child made after playing the Forces-of-Nature Theatre. Right: Part of the physical laboratory preceding the activity.

Before running lessons in selected schools we prepared teachers. In 2020 lessons started that involved c.a. 900 students in 5 countries. However, national differences required some modifications of the didactical material.

National contents

As already said, specific social contexts in different states force us to adopt slightly modified contents for teaching in, say Denmark, Germany and Poland, see fig. 8. below.



FCHgo! Discover the energy of hydrogen

D3.3 – First report on educational outcome

Version 2.0

3a. National priorities

As specified above, the educational material has been adopted to specific national priorities. In Poland this is a huge air pollution due to burning coal. Denmark has in last 20 years 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, do 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 pictures below from lesson prepared by prof. Anke Hagen from DTU.

(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 Dec. 2016: they do not meet each other.

Also in Germany it is well understood the need for new energy policies: productions and storage. Here below 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).

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.

Additional educational/ dissemination material produced at UMK: (a,b) "Water driven car" - a paper published in *Physics in School* (1st and 6th page). (c) Series of 5 lessons registered in Italian (and Polish) for secondary schools - teachers and students. Lessons No. 4. "Hydrogen fuel cell", https://youtu.be/dlbEz0OMEMU

4. Current activities in schools

Fig. 8. The national differences in FCHGo: In Denmark and Germany the main macroeconomic problem in energy policies is to create some storage margins, in Poland – the challenge is to substitute coal with other energy "sources".

In Denmark in twenty years 2004-2016) the coal has been substituted by wind as the source of electricity. However, the wind does not guarantee a constant level of the delivery of electricity. As far as other countries use other energy sources (for ex. the nuclear one), it is possible to compensate the fluctuation. A study by the German Association of Hydrogen (middle panel in fig. 8) shows a similar mismatch in delivery and consumption of the electricity in Germany: there are not currently any capacities of the energy storage to compensate periodical shortages. For Poland the main problem is the predicted deficit in the production of electricity (due to finishing resources of coal) that without any structural changes may reach 30% of the demand in 2040. At the same time the air pollution in Poland (monitored as benzopirene) exceeds by a factor of 10 the level in the rest of Europe, see our didactical paper in Polish "Physics in School" (Karwasz et al. 2019).

Activities in schools

In the first part of the Project, with the didactical material still in preparation (and translations) lessons in different countries followed somewhat different scenarios. In Poland we concentred on rising the social awareness on the global warming and the atmospheric pollution (in secondary schools) and on the phenomena of electricity and hydrogen in primary schools. In Switzerland (and Italy) lessons in primary schools followed more strictly the metaphoric approach, as children had already some notions on the electricity. As seen from fig. 9, the lesson (run by ZHAW expert Erwin Hounder) at the 4th grade of primary school Winterthur was based on "ghosts" to explain the energy fluxes and transformations.

Fig. 9. Narration and metaphor used in teaching on hydrogen, sun and energy carriers in elementary schools in Switzerland (Winthertur, January 2019). Teacher Erwin Hounder.

In turn, in Poland, pupils enjoyed much simple experiments with electricity (batteries, photovoltaic cells, models of hydrogen-driven cars. They

Fig. 10. Activities in classes 1^{st} & 2^{nd} (7-9 yrs old) in primary schools in Dąbrowa Biskupia and Ośniszczewko (Dec.2019). Teacher: Katarzyna Wyborska.

In secondary schools (in Poland and Italy) we used Power Point presentations and sets of more complex experiments in the electrolysis, hydrogen fuel cells, thermodynamic engines, photovoltaic cells etc, see fig. 11.

Fig. 11. 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) Reception by students (54 persons) I LO Gniezno 25/20/2019; expert G. Karwasz

In total, almost 1400 pupils followed FCHgo lessons. Unfortunately, due to the unpredicted events, in March teaching in classes was interrupted. Some of the material has been delivered on-line, but we missed the completeness of the scenarios.

Preliminary didactical results

Generally, both teachers and pupils were quite enthusiastic about the new didactical approach and specific contents on hydrogen technologies. FCHgo lessons showed that the young generation is already sensible about environment problems but does not see clear solutions.

Post- lessons tests of knowledge in Polish secondary schools showed that “students know quite a lot on the problems of environmental pollution, on climate changes, thay 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.” (dr Anna Kamińska)

Narrative approach was highly appreciated in Italy, where teachers had met it some time before the start of FCHgo Project. Dr Paola Morelli (UNIMORE) commented it:

“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).”

The FCHgo material proved to be a little but too complex for German teachers (that did not follow the same rate of preparation as Italian ones. One of the German teachers commented:

“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.” (Sandrina Felder, Augsburg).

Another teacher (Ulrike Krämer) writes:

“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.”

At the level of secondary schools students were generally much interested and enjoyed in particular interactive experiments. The test performed were multi-choice, but on purpose constructed with no unique correct answer. In consequence, students had some difficulties, as seen from the example below (numbers in parenthesis show the number of students who signed this answer)

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

1. Hydrogen is cheap to be produced. (4)
2. Burning hydrogen does not emit CO_2. (26)
3. Efficiency of fuel cells is, potentially, higher that burning hydrogen in combustion engines. (14)
4. Fuel cells are simpler in construction than combustion engines. (2)

As far as the goal of inducing an own reflection among students was achieved, we lacked the clarity of the didactical message: in the example above we hoped to obtain the majority of answers in point, as the hydrogen fuel cells do not burn hydrogen but perform the chemical synthesis of H_2O. The conclusion is that we must underline better the main points of hydrogen technologies.

In late spring 2019, during lock-down, some activities were proposed on-line. In fig. 12 we show on-line answers of elementary school pupils on photovoltaic and hydrogen technologies.

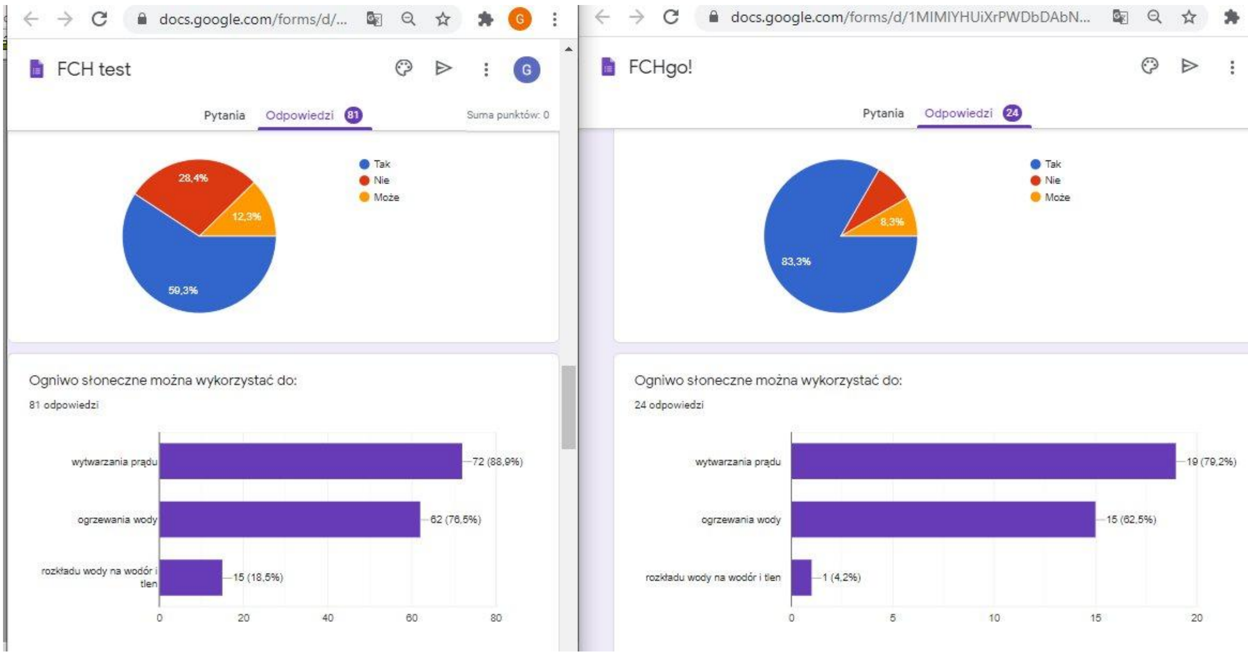


Fig. 12. On-line tests of the didactical outcome of FCHgo lessons in Poland: pupils "trained" from Dąbrowa Biskupia and Ośniszczewko (81 persons, left panel) are compared with 24 pupils who accessed the site on the voluntary basis (right panel). Two chosen questions are shown. The pie graph answers to 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 – Katarzyna Wyborska, May 2020.

Contributions from teachers

The narrative approach was developed in Italian-Swiss university collaboration and as a such implemented in FCHgo didactical model. What is the real added value in the EU-based project is the contribution from other participants, especially teachers, who an a long-run should learn the new methods and contents. Questions asked by one of us (KW) in the environment of a small rural schools in Poland are as follow:

- Why alternative and hydrogen technologies are important?
- Why it is important to teach them in the school?
- Why it is important to teach them in rural schools?

There are many reasons for teaching about renewable energy and hydrogen cells. In first place our students should be equipped with knowledge that will allow them to respond to the needs of the current market and economy. Pupils should know the benefits of renewable energy and hydrogen technology. The most important aspect is taking care of our natural environment. By using renewable energies, we can have a better impact on our environment and reduce smog which has a negative impact on our health. This kind of lessons make a major contribution to promoting the environmental awareness of students. We need to talk about climate change in schools and how it can affect the lives of future generations. We have to convey to students that obtaining energy from sources such as coal or oil has negative and often irreversible effects on our climate. Reliable transferred knowledge on this subject allows to explain the complex physical phenomena occurring during energy transformation, as well as the advantages and disadvantages of these technologies.

An important element in teaching is to show how the use of renewable energy or hydrogen looks like in practice. For this purpose, we use photovoltaic panels, wind turbines, and a hydrogen-powered car. Such methods of conducting classes, used as a tool for developing key competences, are an example of diversifying a standard lesson in physics, technology, nature and a departure from traditional teaching. The obvious argument is to shape critical, logical thinking, planning, reasoning, arguing and anticipating future decisions.

Introducing teaching about renewable and hydrogen energy gives the opportunity to shape the key competences and ecological culture of students from rural areas. The implementation of the FCHgo! project made a huge contribution to energy education in primary school. The proposed teaching concept allowed to inspire students to deepen their knowledge of climate change, renewable energy sources and hydrogen technology. All activities undertaken within the framework of the project had a common goal, supporting the development of students of the school, shaping research attitudes and competences through discovery.

Thanks to such solutions, the school provides access to information that may influence the further choice of educational path or future career. We invite students and teachers to discover hydrogen energy through innovative methods and educational materials to inspire activity in the classroom and beyond.

Conclusions

The Projects, still running, already showed that basic principles of FCH functioning can be easily understood even by youngest pupils. The impacts consist in important aspects of school education, ensuring young minds are adequately prepared for the energy policies, so that ecological thinking becomes an integral part of their lives. The Projects brings also benefits introducing new didactical methods, interesting for teachers. The use of a metaphor, the narrative approach, and interactive experiments proved to bring the real didactical novelty. This, after initial hesitation, was appreciated both by teachers and pupils in all five countries involved. Finally we must stress the high social impact in rising pupils consciousness on the environmental problems and giving information on possible technical solutions, hydrogen technologies in the first place.

Acknowledgements

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