FCHgo: Fuel Cells Hydrogen educational model for schools, an imaginative approach to hydrogen and fuel cell technology for young students and their teachers

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FCHgo: Fuel Cells HydroGen educatiOnal model for schools, an imaginative approach to hydrogen and fuel cell technology for young students and their teachers

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Abstract. In this paper we will describe didactic elements in the Horizon 2020 project FCHgo. This project is directed at children and adolescents between 8 and 18 years old. Its ultimate goal is to raise awareness for renewable energy sources, in particular hydrogen as a fuel and fuel cells for electric power. As part of the project, we are developing a toolkit for teachers and pupils, based upon a narrative approach to physical science and engineering. We believe the narrative approach to be best suited for this project because it allows us to take into account the cognitive tools available to pupils at various stages of their development.

1. Introduction

The purpose of FCHgo (Fuel Cell HydroGen educatiOnal model for schools) is to encourage – in the young generation – a culture of ecological awareness, and to develop behaviours based upon sound knowledge of key technologies. It aims at creating an Educational Program Delivery Model (EPDM) with educational materials for young learners (primary and secondary schools) and their teachers concerned with the science and technology of hydrogen fuel cells, to be used in primary and secondary schools.

We will address a number of challenges inherent in this endeavour. Among these are a lack of basic understanding, by the general public, of the role of energy and energy carriers in physical, chemical, and biological systems; lack of specific knowledge of fuel cell technology (such as the functioning of chemical batteries and fuel cells, the role of hydrogen as an energy carrier); and a lack of understanding of the interaction of technological, environmental, economic, and social systems. Better understanding of such subjects by a larger number of people, from pupils to their families and acquaintances, will be central for technological, economic, and social progress that is to guide and help us through the transformation of society toward sustainable energy systems.

From a scientific and engineering viewpoint, we make use of modern developments in physics, chemistry, and systems engineering, and integrate these elements with the best knowledge of fuel cell and hydrogen (FCH) technologies available today. However, young children cannot be expected to understand such complex systems derived in a top-down approach originating in formal science and engineering. Therefore, we have developed a narrative approach to FCH technologies, suitable to young children and consistent with a formal path without any loss of stringency.

2. Theoretical background: Understanding Nature is a Narrative Affair

The issue of narrative in science and science learning has gained considerable weight in recent years. Usually, it is assumed that narrative plays an important role in putting science in (cultural, social, economic, political…) context and, possibly as a corollary of this use, in creating affect in learners who otherwise find it difficult to relate to and learn about science.

These uses of narrative in science are *extrinsic*. It has become clear, however, that narrative – and storytelling in particular – have an important *intrinsic* role to play as well. "Narrative science" is best known in the realm of natural history (biology, earth science, astronomy and cosmology): in order to understand nature, we need to know its history, and to accomplish this, we need to put our knowledge in narrative form [1].

Recently, an even stronger relation between narrative and science has been researched and argued for. Economists use a narrative approach (they tell themselves stories of dynamics in economic systems) when attempting to construct models [2]. In computational physics and chemistry, large-scale simulations are understood as narratives telling about the "adventures" of physical quantities in natural systems [3]. Engineers use simulations as story-like tools in order to better understand the structure of technical systems for optimizing design [4].

Most important for our purpose, it has been demonstrated that macroscopic physics in the form of continuum physics has a narrative form [5, 6, 7], and understanding of physical and chemical systems takes recourse to our narrative mind.

This work has been applied to university, secondary, and primary education. In the education of engineering students, we have combined a narrative approach to macroscopic physical systems and systems science [4, 5, 8, 9, 10, 11, 12]. A narrative approach to mechanics has been applied to the design of an educational laboratory at Ducati Motor Company in Bologna, which hosts groups of secondary and gifted high school students [13].

Many of the EPDM materials developed for FCHgo are for the younger learners. The approach taken rests largely upon work done at the University of Modena and Reggio Emilia, at the Free University of Bolzano, and at Zurich University of Applied Sciences at Winterthur, over the last 10 years. For an overview and summary see [14, 15]; it covers developments of approaches and materials for student teachers, in-service teachers, and kindergarten and primary school students. Apart from a generalized imaginative approach to physical science for the teachers, we have developed *stories of forces of nature* (including the necessary pedagogical tools for teachers). An animated film of a story of forces of nature "at work" in a technical system [16] has inspired us to create *Forces-of Nature Theatre* (FoN-T) plays where children physically represent processes in natural and technical systems.

2.1. Formal scientific and cognitive scientific background

The development of a generalized approach to (uniform) dynamical physical systems [10] has laid bare the analogical structure of theories of fluids, electricity, heat, substances, and motion. Based upon this work, imaginative cognitive structures have been demonstrated to exist [5, 11] that make it possible for what is normally very formal to be presented in ways employing natural language with its narrative, metaphoric, and analogical tools [6, 7, 14, 15].

One of the graphical tools developed for modelling macroscopic physical and technical systems – so-called process diagrams ([10]; see the examples in Figure 1) – have been a source of both theoretical development in the sciences and engineering [17] and imaginative work at the intersection of science, art, and learning [16]. They are a source for Force-of-Nature Theatre plays (see below) and materials for teachers who are not scientists or engineers themselves.

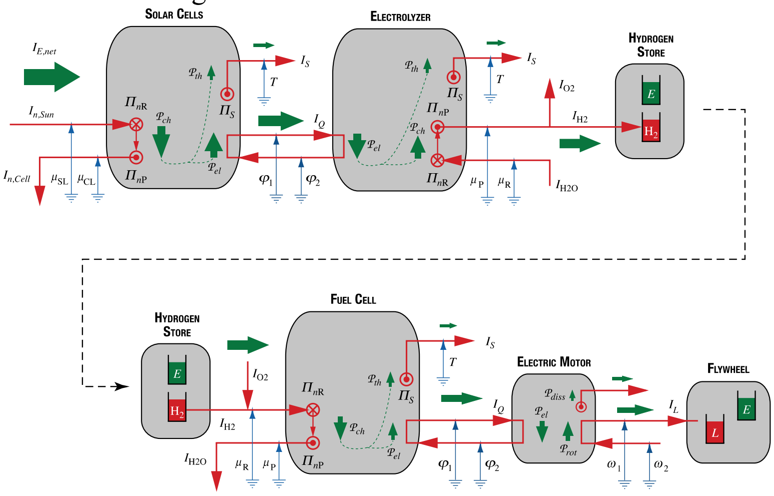

Figure 1. Process diagram for the chain of devices and processes going from sun to solar cells, electrolyzer, and hydrogen storage, and from hydrogen storage through a fuel cell to an electric motor and a flywheel.

Furthermore, the approach to dynamical systems in macroscopic physics has been made possible by computer modelling tools that preserve important elements of the narrative structure of models of natural and technical systems. Some of these tools can be transferred to and used in primary and secondary school settings.

2.2. *Stories of Forces of Nature*

Experience of nature and (dynamical) technical systems leads to the creation in mind of a structure we call *force of nature* (examples: rain, wind, sunshine, soil, food, fuels, electricity, heat, motion…; [14]). These forces of nature are perceived as agentive, even as agents: our language, and our equations in continuum physics, are witnesses of this form of imagination [5, 6, 7].

One of the central arguments of the narrativity of human understanding of nature takes its cue from this imagined agency: Agents (characters, protagonists), along with agency and events, time, and change, are one of the central elements of any story we tell ourselves about happenings in the world (as we maintain, this is true not only of the world of human interactions but also of the interactions of humans with their natural and technical environments). This is important for our ability to create stories of forces of nature [15] that do not only motivate and entertain but suggest how natural agents (forces of nature) relate to each other and to their (physical) environments: this is the source of ideas for (formal) models in science and (informal) forms of expression in everyday life [6]. Most of all, these stories include and give meaning to the notion of energy [18] which is so important to our theme in hydrogen and fuel cell technology.

3. Description of the educational material

3.1. *Apple Story*

A story of forces of nature acting in a setting of interest to our theme is the *Apple Story*. From our point of view, FCH-technology is too complex to be introduced right away to (very) young children. For this reason, we created an illustrated story that draws upon an analogy between food and fuel, and that covers most of the concepts needed to understand fuel cells and the processes therein. The subject of this story – photosynthesis – is intimately related to this technology. It contains the same energy carriers and similar processes (namely, chemical reactions, transport, and storage) as in hydrogen fuel cell systems.

The story is about a girl who eats an apple to “fuel up” and to “get her engines running.” She observes the apple tree in her yard that grows and produces apples. The ghosts, i.e., agents, appearing in this story are light, water, air and food, see Figure 2. Light, water and air combine and disappear, making their energy available that is then used in the production (creation) of a new ghost: food.

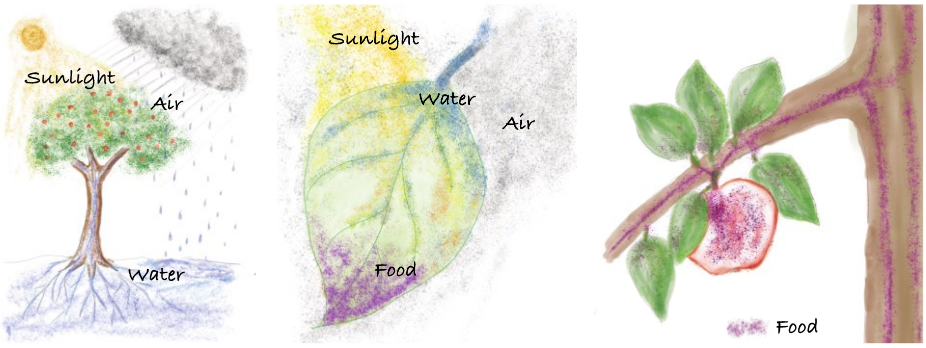

Figure 2. Illustrations from *An Apple Story*. Left: A tree and three forces, sunlight, water, and air. Center: The forces come together in a leaf where they will blend, fade away and create food. Right: The food travels to parts of the tree and into the growing apple.

The Apple Story offers a narrative introduction to the subject of processes and energy and the concepts necessary for younger students (age 6 to 12) to understand hydrogen fuel cell technology. In particular, the story introduces forces of nature as agents in natural and technological processes and energy as a substance-like quantity carried by the forces of nature. The story setting is an everyday-life environment, and tells about food and natural processes, which are familiar to children of age 6-12.

3.2. Perpetuum mobile movie

In 2014, Marion Deichmann set out to explain the inner workings of natural and technical systems in an imaginative manner [16]. Her aim was to study the use of visual metaphors for a thesis in scientific visualization. One of the results, her animated story *Perpetuum Mobile*, has been made available to our FCHgo project and is used as a vehicle for an introduction to the role of *forces of nature* and *energy* in macroscopic physical (and chemical) systems and processes. It is designed as a general introduction to the role of energy in physical systems rather than specifically for hydrogen and fuel cell technology.

The animation tells the story of an inventor who dreams of the perfect perpetual motion engine (Figure 3). When he finally builds it, it seems to work at first.

Figure 3. The *Perpetuum Mobile* machine.

He starts the generator by hand, turning its axle (Figure 4, left). This makes electricity flow which, in turn, lights the lamp. The light of the lamp drives the solar cell (Figure 4, centre) which drives a water pump. The water is pumped high, falls down upon the water wheel (Figure 4, right) which now turns and so drives the generator, and so on, ad infinitum or in perpetuity…

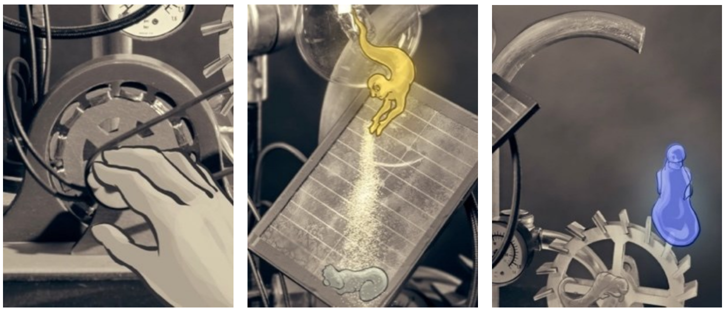

Figure 4. Initially, the inventor drives the generator of the Perpetuum Mobile machine by hand. Light drives the solar cell, a pump pumps water high up whereupon it falls down. There are “ghosts” or “spirits” at work in the machine which play an important role later in the story told here.

However, since every operation produces some heat, the energy made available by the inventor in the initial “push” and then “handed” from part to part inside the machine, becomes less and less. In the end, inevitably, the engine will stop. When it becomes clear that it will never work, the machine is put under a glass cover near a window in the attic of a museum (Figure 5). There, by chance, the sun shines through the window, its light falls upon the solar cell (photovoltaic cell) that is a part of the engine. The engine starts working, the heat generated in every step of the operations lets the glass cover break and so sets the engine free – from now on, it will work “forever,” at least as long as the sun keeps shining, and as long as it does not break.

Figure 5. Put under a glass cover, the machine is tucked away in the attic of a museum. Luckily, its solar cell faces the window. When the sun shines through the windows into the room, the machine starts running. Heat is produced in the engine which breaks the glass cover and finally sets the machine free.

Apart from how the engine works internally, apart from the forces that operate in its interior, there are two noteworthy external circumstances that let the Perpetuum Mobile work. First, there is the sun that sends its light to Earth. Second, the heat invariably produced in any real operation in nature and engines, can escape to the environment and from there to outer space (Figure 6). The engine is a mechanism that works in an open flow system that is the surface of our planet.

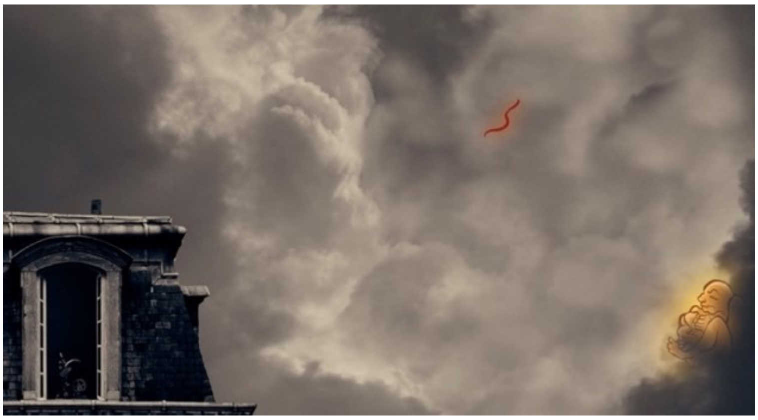

Figure 6. The sun sets, and the heat produced in the operation of the engine escapes to space. The engine can rest; but the forces making it run in the first place will resume their work the next morning.

The story not only explains why a perpetual motion machine cannot work. Embedding the animation in its earthly and cosmic settings, the story is actually a beautiful allegory of our planet as an open system that makes life and the continuation of processes possible.

3.3. Role plays

Visual metaphors telling the story of the interaction of forces of nature in energy systems can also be cast in the form of theatrical plays. We have produced instructions for role plays, where students act as energy carriers in systems that create chains of processes (such as sun to solar cell to electrolysis of water to producing an electric output by a fuel cell to driving an engine or lighting a lamp). Energy is represented by confetti. Actors passing confetti to each other represent the carriers transferring energy. The coupling devices (energy exchangers such as solar cells, electrolyser, fuel cell, etc.) are the places where the actors meet and exchange confetti – they are represented by spaces on the floor where the phenomena are enacted. To design the role play, every group of actors will refer to the "story of energy" of a specific energy carrier. Before the role playing begins, the actors will be assigned their roles and materials; costumes, boards and signs will be produced or made available. The role playing can be filmed for later analysis and discussion.

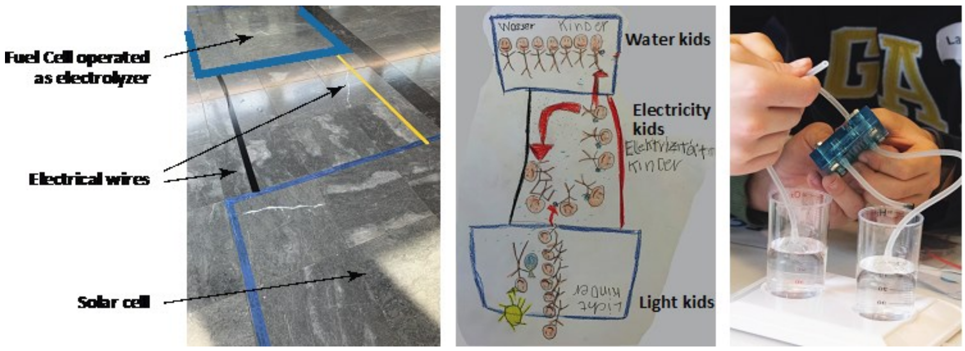

Figure 7. A primary school class in Switzerland (2nd graders) play forces of nature acting and interacting in a lamp-PV-cell-electrolyzer system. Left: The floor with an outline of solar cell (bottom) and electrolyzer (top) with the paths (cables) for electricity between them. Center: A drawing by a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

As an example, consider an electrolyzer (driven by electricity powered by solar cells) producing hydrogen and oxygen from water (Figure 7). The electrolyzer works with electric charge that is pumped by light in a solar cell. With a large enough group of people in such a Forces-of-Nature Theatre, we can assign roles to fairly large teams that each learn to physically represent the properties of a fluidlike quantity – moving (flowing) along paths and expressing degrees of tension (tense or relaxed). Think of a team of children who have been assigned the role of electric charge. They line up along the closed path connecting a solar cell and the electrolyzer (Figure 7, left and centre). Initially, they can all be relaxed. Then, children representing the Sun's light move in one by one. The "light kids" will have been handed confetti – as an analogy to dust/energy in Deichmann's animation – by the "Sun" (maybe played by a teacher), which they now hand to the waiting "electricity kids." A child representing charge who has just received some confetti will become tensed and start moving (the entire loop of electricity kids will start moving).

The tensed electricity kids will eventually hand the confetti they received to "water kids" waiting in the electrolyzer (the floor space representing this device). As they do this, they relax and move back toward the solar cell. The water kids then hand the confetti to hydrogen kids (not shown here; oxygen kids can be included if it seems reasonable). The hydrogen kids then move to a storage device with the confetti in their hands (again not shown here).

There are a couple of interesting things some of the agents have to learn: light kids are "born" at the surface of the Sun and "die" in the solar cell, water kids disappear ("die"), hydrogen kids are "born," and "heat kids" are "born" as they pick up confetti that falls to the floor. In all of this, the persons acting as forces of nature will experience an embodied (physical) logic of what forces of nature can and cannot do, and what happens to energy (confetti) and what not. Just to mention a few points of this logic: agents do not "convert" into one another; agents are not energy; energy is always the same as it makes its way through a chain of devices and processes – energy does not change form or the like.

Note that the energy plays proposed here are considerably different from those introduced by Scherr et al. [19-21] where energy is represented by actors directly without the involvement of the energy carriers. In our scheme, we stress the importance of the carriers [10, 22] as representatives of forces of nature, i.e., of the fundamental quantities that are used in the modelling of processes themselves – in complete formal models, energy takes an "ephemeral" role rather than a substantial or singular one.

3.4. Card Games

There are ways of bringing Deichmann's animation and Forces-of-Nature Theatre plays to the tabletop in the form of card games. Card games are useful for slightly older students (upper primary to middle school); our particular example has been developed for the Ergoland project at the Free University of Bolzano. A card represents an element of a process diagram – an energy carrier, to be precise. A collection of cards allows for process diagrams to be represented in an abbreviated and simplified form (see Figure 8). Energy carriers representing forces are characterized by different levels/potentials. Combinations of carrier/force-cards and physical-element-cards (suitably drawn by the pupils or the teachers and added to the game; see for example the pink framed pictures in Figure 8) allow for short to long chains of processes to be represented.

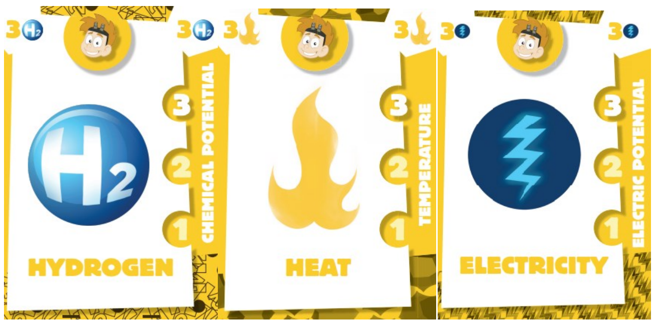

Figure 8. Cards representing forces of nature (as energy carriers) made available through Ergoland. Left: The card developed for hydrogen (like every card, it displays three possible levels, i.e. potentials). Middle: The card developed for heat. Right: The card developed for electricity.

3.5. *Process diagrams*

While empowering the imagination for first steps toward imaginative rationality with the help of stories and Forces-of-Nature Theatre is in the foreground for young children (8-12 years of age), making explicit use of imaginative rationality in the creation of mental and computer models from stories told and re-told, forms the core of a methodology for older students (12-18 years of age).

Stories of forces of nature interacting in chains of processes have been converted to graphical representations [10]– called process diagrams – that use the same image-schematic elements as those that structure metaphors in stories and plays (see Figure 9). Process diagrams provide us with didactic means for older learners where story-worlds (models) are created in a form that is intermediate between story or play and formal computer models. Instructions for how to use simple physical objects for image-schematic elements that allow students to assemble process diagrams for a large range of concrete systems will be made available as part of the educational materials.

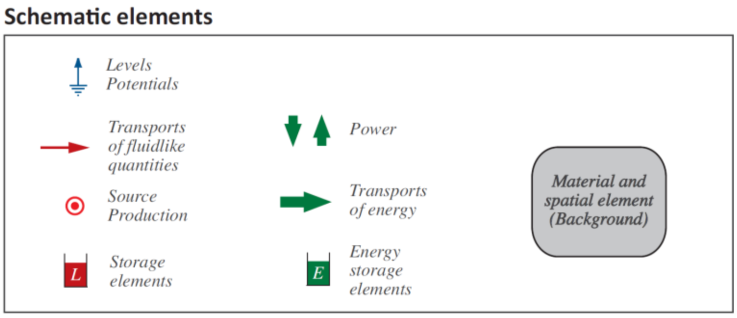

Figure 9. Image-schematic elements for levels (blue vertical arrows), transport, production and storage elements for fluid like quantities (red arrows and containers), as well as power, energy transport and storage (green arrows and containers) are used in process diagrams.

Process diagrams serve as stepping-stones toward formalized representations of what the metaphors tell us about systems and processes, including the role of energy. The schematic elements that appear in a story, such as the intensity, the transport or production of an energy carrier, energy itself and transport of energy can be combined to form visual analogues of metaphors, see Figure 10.

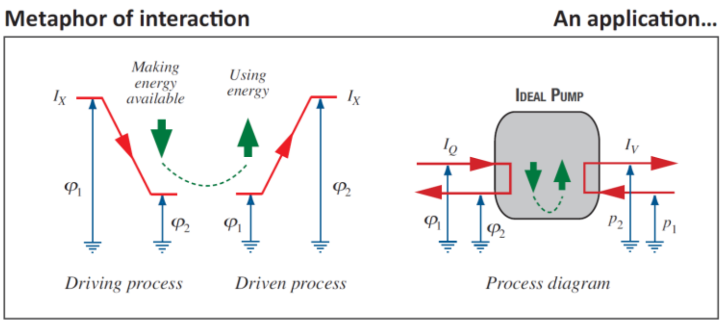

Figure 10. Left: A fluidlike quantity flows downhill and makes energy available; this energy is taken up (used) by another process where a fluidlike quantity is “pumped.” Right: Representation of the interaction of electricity and water in an ideal pump.

In Figure 10 a process diagram of an ideal pump is shown on the right-hand side. It involves two energy carriers: electricity and water. Electricity flows downhill from a higher electric potential to a lower one, thereby releasing energy (making it available). This is symbolized by a schematized waterfall image on the left-hand side. Energy is made available at a certain rate which is the formal concept of power; we denote this by a fat green arrow inside the box pointing downward. Water picks up energy (at a rate again called power): this is symbolized by a fat green arrow pointing upward. As a result of the interaction, water is forced to flow uphill. A new tension (in this case a pressure difference) is established.

3.6. Tools for formalization: System dynamics modelling

Much of the EPDM materials for younger children – primary to middle school – make use of an explicit narrative approach: stories and story-like games. There are didactic tools that allow for transiting from primary to secondary and university education by formalizing yet continuing the narrative forms of explanation we have described here. One such tool is comprised of the family of system dynamics computer modelling programs.

If we represent the pseudo-material character of forces of nature, i.e., their extensive aspect, as fluidlike quantities [10], we can translate the dynamics of such quantities acting and interacting as system dynamics models. System dynamics modelling has been developed for younger learners as well [23] but is most likely of great use for older learners [12].

System dynamics models make use of the imagery of the flow, production, and storage of fluidlike quantities and, in so doing, continue using important elements of narrative understanding of dynamical systems. Interestingly, System dynamics models can be developed for both technical/scientific and social systems. More mature learners can apply the imaginative forms learned in the FCHgo approach to energy systems to systems representing processes in socio-technical systems that are particularly relevant to the development and adoption of future technologies.

4. Conclusion

In conclusion, our methodology is centred on narratives (stories and plays for the youngest, narratives and process diagrams for the older ones, leading to a continuum along which the degree of formalization of the educational process is raised) and provides direct physical as well as mental involvement for pupils. Students and teachers will be involved in telling and creating stories or explanatory narratives and experiencing the assembly and the functioning of simple toys or experimental devices. They will discuss forces of nature acting in the toys and devices, design and play-act how forces of nature act and involve energy, construct process diagrams with more or less formalized iconographic materials, reflect upon FCH technology, applications, and job opportunities. The EPDM will provide didactic materials and teacher guides for the network of schools and stakeholders that will make use of this project.

According to the project schedule, we are in the phase of experimentation with the EPDM materials and of collecting feedback from experts, teachers, and pupils to assess, revise, validate and further develop the EPDM products.

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5. References

[1] Norris S P, Guilbert S M, Smith M L, Hakimelahi S, Phillips L M 2005 *Science Education* **89(4)** 535–563
[2] Morgan M S 2001 *Journal of Economic Methodology* **8(3)** 361–384
[3] Wise M N 2011 *Erkenntnis* **75(3)** 349–376
[4] Witzig A, Borth J, Danesi S 2018 *International Solar Energy Society: EuroSun 2018 Conference Proceedings*
[5] Fuchs H U 2014 50–61 *C. P. Constantinou, N. Papadouris, & A. Hadjigeorgiou (Eds.), E-Book Proceedings of the ESERA 2013 Conference: Science Education Research for Evidence-based Teaching and Coherence in Learning. Part 1. Nicosia, Cyprus: European Science Education Research Association. European Science Education Research Association*

[6] Fuchs H U 2015 *International Journal of Science Education* **37 (5-6)** 934-957
[7] Fuchs H U, Contini A, Dumont E, Landini A, Corni F 2018 *Narrative and Metaphor in Education: Look Both Ways*, p 91 (Routledge, Abingdon, UK and New York)
[8] Fuchs H U 2006 *Proceedings of the 2006 GIREP conference. University of Amsterdam*
[9] Fuchs H U 2010 *Rev. Cubana de Física* **27 (2A)** 119-124
[10] Fuchs H U 2010 *The Dynamics of Heat* (Springer, New York)
[11] Fuchs H U 2014 *Energy Harvesting Systems* **1(3–4)** 253–265
[12] Dumont E, Fuchs H U, Maurer W, Venturini F 2014 *The 9th international conference on conceptual change, Bologna, Italy 2014, August*
[13] Corni F, Fuchs H U, Savino G 2018 *International Journal of Science Education* **40(3)** 243–267
[14] Corni F, Fuchs H U 2020 *Primary Physical Science for Student Teachers at Kindergarten and Primary School Levels: Part I—Foundations of an Imaginative Approach to Physical Science* (Interchange) doi.org/10.1007/s10780-019-09382-0
[15] Corni F, Fuchs H U 2020 *Primary Physical Science for Student Teachers at Kindergarten and Primary School Levels: Part II— Implementation and Evaluation of a Course* submitted.
[16] Deichmann M 2014 *Im übertragenen Sinne. Metaphern und Bildvergleiche in der Wissernschaft* (Bachelor thesis) Zürcher Hochschule der Künste. http://vimeo.com/98311515
[17] Tyreus B D 1999 *Ind. Eng. Chem Res* **38**, *1432-1443*
[18] Fuchs H U, Dumont E, Corni F 2019 *From Metaphor to Narrative in Macroscopic Physical Science* (F. Corni, T. Altiero, & A. Landini (Eds.), Innovazione della didattica delle scienze nella scuola primaria e dell'infanzia: al crocevia fra discipline scientifiche e umanistiche. CLEUP)
[19] Scherr R, Close H, Mckagan S, Vokos S 2012 *Physical Review Special Topics - Physics Education Research* **8** 020114-1
[20] Scherr R, Close H, Close E, Vokos S 2012 *Physical Review Special Topics - Physics Education Research* **8** 020115-1
[21] Scherr R, Close H, Close E, Flood V, Mckagan S, Robertson A, Seeley L, Wittmann M, Vokos, S 2013 *Physical Review Special Topics - Physics Education Research.* **9** 020105-1
[22] Falk G, Herrmann F, Bruno Schmid G 1983 *Am. J. Phys*. **51** 1074
[23] SDEP MIT 1996 http://web.mit.edu/sysdyn/index.html and http://web.mit.edu/sysdyn/road-maps/toc.html.