Using a hydraulics bench to investigate 6th grade students' energy conceptions

ASIMINA DALAPA, VASILIKI EVANGELIA VAYENA, NIKI SISSAMPERI, DIMITRIOS KOLIOPOULOS

Department of Educational Science
and Early Childhood Education
University of Patras
Greece
dkoliop@upatras.gr

ABSTRACT

Being an abstract, purely mathematical concept with varying definitions across science disciplines, energy constitutes an abiding challenge for both teachers and learners. Taking into account research on model-based learning in science education, we investigated 11-12 year-old students' conceptions about energy in a university laboratory using a hydraulics bench intended for training Engineering students. The original set-up was modified to simulate a hydroelectric power station. Participants were given a list of activities and worked in groups. Their discussions were recorded and later debriefed. Field notes were also taken. Research data and results are presented and discussed.

KEYWORDS

Hydraulics bench, energy conceptions, model-based learning, primary education

RÉSUMÉ

En tant que concept abstrait, purement mathématique, avec des définitions variables selon les disciplines scientifiques, l'énergie constitue un défi constant pour les enseignants et les apprenants. Tenant compte de la recherche sur la modélisation dans l'enseignement des sciences, nous avons étudié les conceptions énergétiques des élèves de 11-12 ans dans un laboratoire universitaire en utilisant un banc hydraulique destiné à la formation des étudiants ingénieurs. La configuration initiale a été modifiée pour simuler une centrale hydroélectrique. Les participants ont reçu une liste d'activités et ont travaillé en groupes. Leurs discussions ont été enregistrées et ensuite débriefées. Des notes de terrain ont également été prises. Les données de recherche et les résultats sont présentés et discutés.

MOTS-CLÉS

Banc hydraulique, conceptions énergétiques, modélisation, éducation primaire

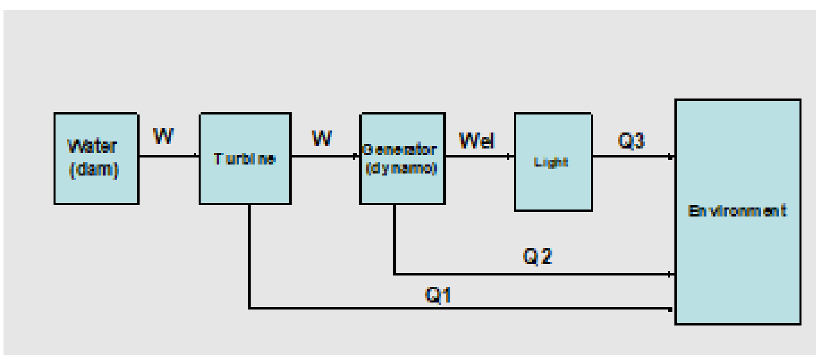
THEORETICAL FRAMEWORK

The aim of this study was to detect 11-12 year-old students' conceptions about energy in an environment intended for teaching university students and conducting research. An original set-up mounted on a hydraulics bench was modified to simulate a hydroelectric power station. Participants were probed to observe it closely and describe how it works. The role of the hydraulics bench is deemed important given that physical models constitute a core element in energy teaching in both formal and non-formal educational settings (Evagorou, Erduran & Mäntylä, 2015). The set-up was adjusted in order to support hands-on activities designed to facilitate exploration (see "Methodology"). The purpose of the activities was to detect children's ideas regarding the following dimensions of understanding of the physical model: (a) the technological dimension (the set-up as a whole and the parts it consists of), and (b) the scientific dimension (the set-up as an energy system) (Sissamperi & Koliopoulos, 2015; Stavropoulos & Koliopoulos, 2018).

Describing the set-up as a technological system (i.e. trying to identify the parts of the system and their function) deploys children's systemic thinking. This is a stepping stone for describing the physical model as an energy system in terms of energy chains. Although energy chains are abstract models, research supports that they can be used effectively by young children when describing qualitatively the function of simple, small-scale energy systems (Delegkos & Koliopoulos, 2018; Koliopoulos & Argyropoulou, 2011) or by older children when describing how systems of larger scale and complexity work (Sissamperi & Koliopoulos, 2015).

Energy chains are a symbolic representation of the structure and function of energy systems. This explanatory model, according to the authors who introduced it, allows students to describe and explain the functioning of a system using the following basic energy concepts: storage, transfer and transformation (Lemeignan & Weil-Barais, 1994; Tiberghien & Megalakaki, 1995). In the energy chain, energy storage and converters are represented with rectangles, and transferred energy with arrows. This facilitates the description of the system's structure, the function of each separate part, as well as the interaction between parts. In Figure 1, a simplified energy chain of the hydraulics bench model is presented.

FIGURE 1



Energy chain depicting schematically the hydraulics bench model

In the Greek curriculum, by 6th grade, students have been introduced to sources and forms of energy, as well as energy transfer and conservation. However, the school textbooks make no reference to energy chains.

Therefore, the research questions we addressed were the following:

a) In what extend students identify the hydraulics bench model as a technological system (i.e., locate the main parts and describe their interaction)?

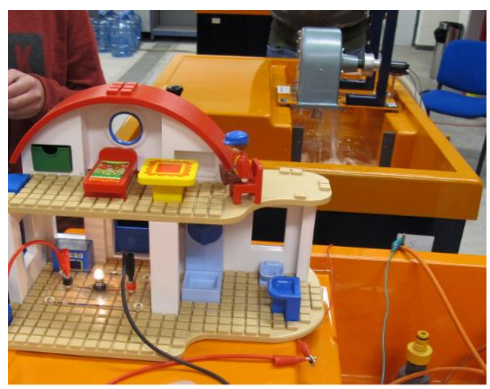
b) How feasible is for 6th graders to use an explanatory energy chain model in order to describe and explain how a complex energy system such as the hydraulics bench model works?

METHODOLOGY

The set-up

The hydraulics bench we used is part of the standard equipment of the Hydraulic Engineering Laboratory at the Department of Civil Engineering of the University of Patras. It is normally used by engineering students during fluid mechanics courses. The set-up we designed was a modified version of the F1-25 Pelton Impulse Turbine by Armfield Co (Figure 2a). The main parts of the original set-up, mounted on a hydraulics bench, are a miniature turbine wheel inside cast housing with acrylic panel to enable viewing, an inlet pressure gauge to measure pressure at the spear valve and a dynamometer with spring balances intended to measure mechanical torque. The flow of water, which sets the Pelton wheel in motion, is controlled by a spear valve. The pressure gauge allows the inlet pressure of the turbine to be monitored. A band brake connected to the spring balances allows the load applied to the turbine to be varied. In the modified version, we removed the dynamometer and added instead a bicycle dynamo and wires leading to a light bulb inside a toy house approximately 1m away. Therefore, the modified set-up (hydraulics bench model) (Figure 2b) simulated a hydroelectric power station in the following way: spear valve (water supply), Pelton wheel (turbine), bicycle dynamo (generator), wires (power lines), light bulb (light generation).

FIGURE 2

	
Figure 2a	Figure 2b

The original (a) and modified (b) set-up fitted to the hydraulics bench

The methodological framework

The methodology used in this case study is based on focus group discussion (Cohen, Manion & Morrison, 2007). The non-probability sample comprised 12 students split in 3 groups. All students came from the same primary school situated close to the University of Patras. They were invited to participate in the research outside school hours by their teacher, who is a member of the research team. Participation was optional and parental permission was required. Students were given a list of activities; all activities were cooperative and participants were encouraged to talk freely and exchange ideas within the group. They were probed to clarify what they observed when the physical model was turned off (in the beginning) and then on. Afterwards they were asked to infer the system's function and to form the energy chain describing its operation using nine cards with the words "water", "turbine", "generator", "bulb", and "environment", or arrows on them. Two of the researchers intervened to challenge students to clarify the ideas they expressed and/or come to conclusions. We opted for focus group discussion in order to flexibly support in-depth interviewing, when appropriate, with the aim to capture rich, descriptive data. Dialogues were recorded and transcribed. Field notes were also taken by the third researcher to facilitate accurate transcription.

The activities were the following:

a) *First activity:* Students were asked to observe the set-up (while turned off) and to infer what it is and what it does.
b) *Second activity:* Students were asked to identify the parts it consists of and to write them down (while turned off).
c) *Third activity:* Students were asked to observe the set-up (while turned on) and to form the energy chain using given cards.

Data analysis

The collected data are qualitative. To meet the page limit, in the following we analyse data from only one group – albeit representative, in the sense that it encapsulates answers given by both other groups. In that group, the members were three boys (Christos, Konstantinos, Dimitris) and one girl (Aristea). Dialogues are presented and analysed per activity:

First Activity

The answers given show that the students guessed how the system works pretty accurately depending only on what they observed before setting the set-up in motion. Christos, for example said, pointing at the Pelton wheel, "*Electric energy is produced by spinning this thing*". After varying opinions had been expressed within the group concerning the parts of the system, the final remark by Aristea was that "*Yes, whatever this thing is, it produces energy*". Following this statement, one of the researchers interacting with the students posed the probing question "*And how does this happen?*". Students observed the set-up more carefully and pointed at the parts in sequence, presenting them like a chain of objects interacting with each other. The words they used implies the idea of energy transfer. Christos, for example, said, while pointing consecutively at the spear valve, the turbine, the dynamo, the wires and the light bulb, "*It goes from here, it goes here, it goes here, here-here and it becomes energy*". Aristea added "*It is electrical energy*". In this episode Dimitris and Konstantinos did not participate actively.

Second Activity

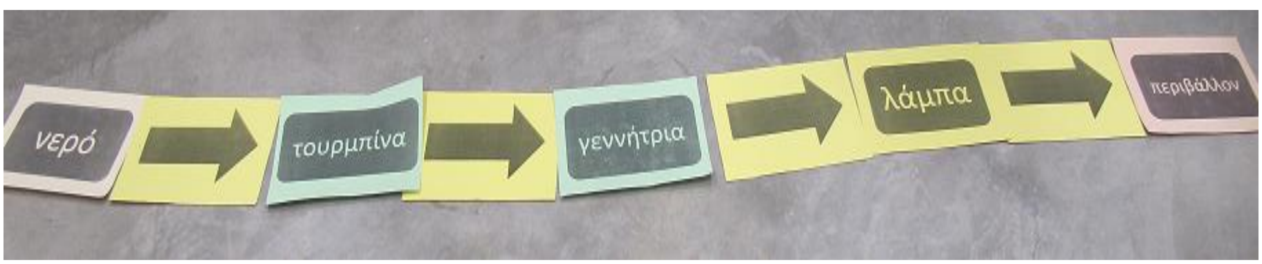
The aim of the second activity was to direct participants' attention towards the technological dimension of the set-up. The students tried to locate the parts of the set-up, name them and infer their function. Dimitris and Konstantinos took a more active role in this episode. Dimitris said while pointing at the sump tank supplying water to the upper part of the hydraulics bench through a vertical pipe with the aid of a pump: "*Water comes from down here*". He went on pointing at the Pelton wheel, "*It spins this thing. It goes here, which I do not know what it is, then it goes there. It becomes electrical energy and goes into the wires*". Konstantinos added "*Wires, toy house, lamp,* *light, the end*". At this point, the researcher repeated the question "*So, what do you think this set-up does*?" All the boys answered "*Light*" but Aristea specified that "*It produces electrical energy*". It seems like the boys focused on the apparent result of the system functioning, i.e., the light coming out of the bulb, while Aristea emphasized the general function of the set-up.

On the one hand, their answers show that they inferred the role and function of the set-up as an energy system before switching it on. On the other hand, they did not identify all the main parts and their role in the system. Although they named "*water*", "*wheel*", "*wires*" and "*light bulb*", they did not locate the dynamo, which is a fundamental part of the system. This probably explains why later on, while trying to put together the energy chain, they confused the turbine with the generator. An interesting debate sparked off when the researcher asked the question *"How does the system produce light or electrical energy?*". They all understood that water movement is a key point in order to set the system in motion. They then listed forms of energy they had been taught in school, trying to describe the energy transformation process. When Christos said, "*It is kinetic energy"*, Dimitris added "*But it becomes electrical*". Konstantinos could not follow the train of thought of his classmates and at some point said, "*I am confused*". Dimitris went on and explained, "*And then it becomes light*". At the end of the second activity the model was switched on, and the students were enthused to see that their prediction was correct (i.e., that when the set-up was set in motion, the light bulb turned on).

Third Activity

The aim of the last activity was to detect students' understanding of the scientific explanation of the set-up functioning. Students were asked to form the energy chain model using five cards naming the main parts of the set-up (water, turbine, generator, bulb, environment) and four cards on which transferred energy was represented by arrows (Figure 3).

FIGURE 3



Cards placed by the students in the following order: water – turbine – generator – light bulb – environment (after the discussion with the researchers)

All participants were thoroughly engaged and collaborated productively, particularly when trying to clarify the role of the turbine and that of the generator. They eventually placed the cards in the right order and the researcher asked, "*Do the arrows just show direction or do they mean something?*". Christos responded first and said, "*Water goes to the turbine, then it goes to the generator, then it goes to the bulb and then to the environment*" and added "*They show energy*". In this statement it seems as if it is the water that moves to the bulb and then to the environment, but he obviously implies electrical energy and light energy, as we can deduct from his final response. The energy transfer and transformation concepts are not concrete. When the researcher tried to clarify their ideas and asked "*Energy? Are all the arrows the same?*", Christos was not sure and said, "*They are the same, b…uuut energy changes*", and Aristea added, "*I think for the water to go* there *[she points at the turbine card] potential energy is needed, then it becomes kinetic, then it becomes light energy, no then it becomes electrical, then it becomes light energy and then it goes to the environment*". Aristea may have named the different forms of energy correctly, but when probed to clarify what potential energy is, for example, she replied, "*It applies force to the turbine*" (note: in Greek, "potential (energy)" and "force" have the same root.) Moreover, when the researcher asked: "*When does energy become electrical? Before or after the generator?*" neither Aristea nor the boys could answer. And not only that, but the confusion regarding the role of the turbine and the generator surfaced once more and the students contemplated rearranging the order of these two cards in the energy chain. The researcher urged them to observe the set-up carefully once more in order to confirm the sequence of the parts represented in the energy chain.

DISCUSSION AND IMPLICATIONS FOR TEACHING

The main finding with regard to the first research question was that students intuitively approached the set-up as an energy system and tended to describe and explain the function of the set-up in energy terms, before identifying the parts of the system and the interaction thereof. This may be due to the fact that they had been taught this terminology in school. However, they do not appear to have an adequate understanding of the energy terms they alluded to. The inaccuracies in their description of the set-up as an energy system is to be expected judging from the fact that their description of the technological dimension of the system was incomplete. Another finding is that, after appropriate guidance from researchers, students perceived the phenomenological and technological features of the system, which are prerequisites in order to construct the scientific knowledge, particularly in the case of complex technological systems (Sissamperi & Koliopoulos, 2015).

As for the second research question, our findings provide supporting evidence that the effectiveness of the forms of energy approach, to which the students referred spontaneously, is questionable. The "forms of energy" approach has been criticized because it teaches students a set of labels that do not promote their level of understanding of processes (Millar, 2014). In the recorded dialogues there was also evidence that students often confuse related yet distinct terms, e.g. "energy" and "force". Concurrently, according to the data analysis, we can support that it is feasible for 6th graders to use the explanatory energy chain model in order to describe and explain how a complex energy system works. Using linear causal reasoning and systemic thinking, the students succeeded in placing the energy chain cards in the correct order. Nevertheless, when asked to explain the energy chain they formed, they realized they had not correctly identified all parts of the set-up, namely they had missed the generator. These results lead to the hypothesis that, following appropriate teaching intervention, children at the age of 11-12 can apply the model of energy chains, which is a semi-quantitative way of explaining natural and technological phenomena, to describe physical models such as the set-up mounted on the hydraulics bench. This hypothesis is in line with results in recent, related studies (Boyer & Givry, 2018; Delegkos & Koliopoulos, 2018; Papadouris & Constantinou, 2016).

Last but not least, this collaboration between the University of Patras Department of Civil Engineering and the Department of Educational Science and Early Childhood Education may pave the way for joint, multidisciplinary efforts to exploit, via thoroughly-planned educational interventions, university assets and resources so as to improve K-12 science education and/or training of pre-service teachers. As far as energy is concerned, even after teaching seldom do students use the concept of energy effectively (Koliopoulos, 2014); there is need and ample room for effective energy teaching and learning in both formal and non-formal educational settings.

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