Teaching energy concepts in complex technological systems: The case of the car

VASILIOS STAVROPOULOS, DIMITRIS KOLIOPOULOS

Laboratory of Didactic of Sciences, Mathematics and ICT
Department of Educational Sciences and Early Childhood Education
University of Patras
Greece
vasta5@yahoo.gr
dkoliop@upatras.gr

ABSTRACT
This study focuses on a section of a broader research concerning the analysis, design and evaluation of a teaching proposal for the concept of energy in a complex technological system (the car), addressed to students of Greek Junior high school (12-13 years old). In particular, we present the design principles, the structure and some aspects of a teaching proposal, which aims to overcome the cognitive difficulties that can possibly emerge in the classroom environment during the teaching of this subject.

KEYWORDS
Complex technological system, car, energy, environment, secondary education

RÉSUMÉ
Cette étude porte sur une partie d'une recherche plus large qui concerne l'analyse, la conception et l'évaluation d'une intervention didactique pour enseigner le concept d'énergie à partir d'un système technologique complexe (la voiture). Cette intervention s'adresse aux élèves du collège grec âgé de 12 -13 ans. En particulier, nous présentons les principes de conception, la structure et certains aspects du contenu de l'enseignement visant à surmonter les difficultés cognitives des élèves pouvant éventuellement survenir lors de l'enseignement de cet objet scolaire particulier.

MOTS-CLÉS
Système technologique complexe, voiture, énergie, environnement, enseignement secondaire

INTRODUCTION

The cognitive and teaching difficulties of the energy concept have been well-known to educators for many decades (Chen et al., 2014; Doménech et al., 2007; Driver & Millar, 1985; Koliopoulos & Tiberghien, 1986; Lemeignan & Weil-Barais, 1994; Tiberghien, 1996). In this context, it has been pointed out that the various forms of the "energy chain" model can be a suitable teaching transformation of scientific knowledge into school knowledge, even for very young ages (Delegkos & Koliopoulos, 2018; Koliopoulos & Constantinou, 2012; Papadouris & Constantinou, 2016; Tiberghien & Megalakaki, 1995).

However, in reference to afore-mentioned ages, both the international and the Greek literature contribute surprising little to the challenge and difficulties of energy teaching for complex technological systems, such as the power stations or vehicle systems. Tese difficulties arise due to the nature of this complex knowledge (which at the same time presents technological, scientific and social characteristics) as well as the capacities and limitations of the students' thinking (systemic thinking, linear causal reasoning) to whom this teaching is addressed (Sissamberi & Koliopoulos, 2015; Stavropoulos, Sissamberi & Koliopoulos, 2010).

This study focuses on a section of a broader research concerning the analysis, the design and the evaluation of a teaching proposal for the energy concept in a complex technological system (the car) addressed to students of the Greek Junior high school (12-13 years old). In particular, we present the design principles, the structure and some elements of the content of a teaching intervention, which aims to overcome the cognitive difficulties that can possibly emerge in the classroom environment during the teaching of this subject.

THE EPISTEMOLOGICAL DIMENSION OF THE EXPECTED SCHOOL KNOWLEDGE

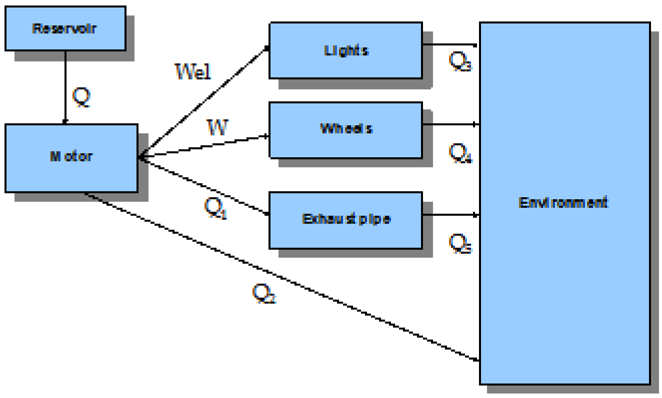
In recent years, natural sciences tend to become the subject of education for more and more people at increasingly younger ages in the context of a broader aim towards "scientific literacy" (Fensham & Harlen, 1999; Millar & Osborn, 1998). One of the elements contributing to the fulfilment of this aim is the upgrade of the cultural component of scientific knowledge in the modern science curricula, particularly in those that are related to the teaching of energy. The different aspects of this educational aim are (a) the inclusion of historical and philosophical elements in the teaching of natural sciences, (b) the organic connection of the scientific knowledge with social and environmental problems and (c) the association with other scientific disciplines or social activities such as mathematics, engineering, arts and technology (STEAM) (Bächtold & Guedj, 2014; Doménech et al:, 2007; Jin & Wei, 2014).

In addition to the scientific dimension, the school knowledge of the energy approach for complex technological systems (the car, in our case) acquired by children at the beginning of secondary education, requires two more dimensions: the technological and the environmental. The environmental dimension refers to the effects of the various types of vehicle on the environment. The main guiding theme for the expected school knowledge is the exploration and comparison of the environmental impact of a conventional, an electric and a solar car. It has been pointed out that pupils are generally more enthusiastic and pay full attention when social factors and special environmental issues are involved in the teaching-learning process (Hobson, 2006). Other researchers mention that the environmental issue can increase high school students' motivation (Batterham, Stanisstreet & Boyes, 1996; Lester, Ma, Lee & Lambert, 2006). It has been argued that bridging the car (as a concept) with the environment can possibly overcome misinterpretations and misconceptions thus leading the students towards a deeper comprehension of abstract environmental issues and the related technological issues (Gayford, 1986; Oulton & Scott, 1992).

The technological dimension of school knowledge includes the description and the operation of the various subsystems and components for each type of car. Understanding the structural and functional characteristics of the car is not a simple process, since the interactions between the subsystems and their components are usually vague. Even for younger students, the construction of knowledge concerning complex mechanical systems can be achieved through a process of modeling - designing - testing and the repeating of this succession, until new, more sophisticated interpretation models have been established (Penner, Giles, Lehrer & Schauble, 1997). Designing-type activities allow the detection of the operation mode of complex technological systems and can enable the students to develop a deeper understanding of them (Hmelo, Holton & Kolonder, 2000). Also, static or dynamic car models can be used to clarify the structure and the overall operation of the system.

The scientific (energy) dimension is the core of the expected school knowledge. It is a teaching rendering of certain energy concepts as they have been formed within the framework of engineering thermodynamics. More specifically, the model of "energy chain", which is a semi-quantitative way of explaining natural and technological phenomena, has been selected as the appropriate didactical transposition for this framework. We have already pointed out in previous works that this model is an appropriate form for teaching energy both for the upper and lower secondary levels, regarding at least the simple small-scale technological systems (Delegkos & Koliopoulos, 2018; Koliopoulos & Ravanis, 2000). Our hypothesis is that children at the ages 12 to 13 can apply this model to describe small technological systems used in school lab as well as complex technological systems such as the car.

FIGURE 1



Representation of a conventional car energy chain

One of the reasons that demonstrate the effectiveness of this model in teaching, is the model's representational power (Figure 1). Such representations are compatible with both the systemic thinking features and the so-called linear causal reasoning. The research on systemic thinking shows that the students can understand some concepts related to certain complex systems even at the level of primary education (Jacobson & Wilensky, 2006). In this direction, the teaching suggestions of Huis & Berg (1993) and Jewett (2008) present a particular interest as they are associated with the teaching of energy in secondary school. In addition, it has been acknowledged that triggering the students' linear causal reasoning can lead to the construction of "qualitative" explanatory models for energy from their side, such as the representations of "function" and "distribution" (Lemeignan & Weil-Barais, 1994).

The interconnection of the three above-mentioned types of knowledge, and especially the one between the scientific and the technological knowledge, is a goal for the research in Science and Technology teaching at large as well as for this specific teaching proposal. In regard to the contradistinction between science and technology, in some cases science plays the primary role, while in some other cases technology takes the lead (Layton, 1993). In both cases, however, students can engage in an open and creative process inspired by scientists and engineers, with the teacher's guidance and assistance (Gil-Pérez et al., 2002).

In the present study the emphasis is placed on the use of a technological framework for constructing concepts that derive from the scientific knowledge context. The teaching of scientific concepts through technological elements is used in this project not only because this is required by the corresponding curriculum, but mainly because the technology-centered activities focus on constructing robust artifacts and representations rather than abstract cognitive presentations (Roth, 2001). Furthermore, this crucial characteristic appears to be compatible with the pupils' cognitive abilities for the ages that this teaching intervention is directed to.

STRUCTURE AND CONTENT OF THE TEACHING SEQUENCE

The knowledge we seek to be integrated by the students relates to the technological, scientific and environmental elements from the reference knowledge of engineering thermodynamics. More specifically, we ask the students to:

- distinguish car parts and describe their technological operation and role.
- describe and symbolically illustrate the motion of the car by using the "energy chain" model.
- perceive and record the environmental impact of car operation and propose solutions, improvements and alternatives to the existing conventional gasoline-powered car.

TABLE 1
Structure and content of the teaching intervention

Unity	Basic 'activity – problem'	Dimensions of expected school knowledge
1	What are the basic parts of a conventional car?	Technological dimension (description of the subsystems and components of a car model)
2	How does a conventional car move?	Technological dimension (description of the operation of a car model)
3	Why does a conventional car move?	Scientific dimension (construction of a qualitative representation of the energy chain model)
4	What happens when we turn the lights or the air conditioner on, while the conventional car is moving?	Scientific dimension (construction of a semi-quantitative representation of the energy chain model)
5	When is a conventional car energy efficient?	Scientific dimension (refinement of the semi-quantitative representation of the energy chain model - introduction to the concept of energy efficiency)
6	What is the environmental impact when the conventional car is moving?	- Scientific dimension (refinement of the semi-quantitative representation of the energy chain model through the concept of energy losses) - Environmental dimension (description of the environmental impact of conventional car operation)
7	How can we reduce the harmful environmental impact of a conventional car?	- Technological dimension (identification of technological elements contributing to environmental pollution) - Scientific dimension (application of the semi-quantitative representation of the energy chain model) - Environmental dimension (restriction of the environmental impact of conventional car operation and suggestions for clean energy car models)
8	What are the technological differences between an electric and a conventional car?	Technological dimension (comparison of the structure and operation of various types of vehicle)
9	What are the energy differences between an electric and a conventional car?	Scientific dimension (application of the semi-quantitative representation of the energy chain model in various types of vehicle)

The teaching intervention we propose consists of a teaching sequence of nine modules divided into two parts. In the first part, the intervention focuses on the study of the conventional car, and specifically its structure, its individual subsystems, its parts' operation, and also to the energy behavior and its environmental impact. The technological object used as the main phenomenological field is a functional model race car with internal combustion engine. In the second part, the teaching intervention focuses on the identification of the harmful environmental impact of the conventional car operation, the highlighting of "clean energy" car technology and on the study of the electric car. The structure of the content of the teaching sequence is presented in Table 1.

APPLICATION EXAMPLES OF THE PROPOSED TEACHING INTERVENTION

Each module of the teaching intervention is accompanied by a worksheet. Every worksheet is based on a main 'activity – problem', around which the students are asked to work according to principles of the inquiry-based teaching approach. According to this approach, the construction of knowledge can be achieved through a process of exploring and interacting with the subject of teaching through effective conversations between students and between students and the teachers.

An interesting example is that of the 4th activity, where the teacher provides a worksheet in order to guide students to construct a semi-quantitative representation of the energy chain model. The key question concerns a car that while its speed is 80 km/h the driver turns on the lights and the air condition without changing the throttle pressure. Students are asked about what will happen with the speed of the vehicle, by giving a justification for this change, and also modify the basic energy chain that corresponds to this act of the driver. The whole process is based on the expression of student's conceptions as they propose and substantiate their views while they discuss with the teacher and their classmates. The teacher focus to energy issues and in particular to the changes that the activation of the additional systems causes to the energy chain.

Another typical example is the 7th activity. After observing the operation of a car model with an internal combustion engine, students are asked to record the types of pollution it causes and the components from which it originates. Students are also asked to enrich the system's energy chain with the thermal losses and to propose modifications or another "cleaner" type of car. For example, in order to eliminate the polluting exhaust, a non-combustion engine is needed. Students propose electric and solar vehicles. This is the starting point for further study of the electric car and comparison to the conventional one, that corresponds to the next activities of the teaching intervention.

EPILOGUE

The proposed teaching intervention and its design principles negotiated in this work, have already been applied to school classes of the Greek state school and we have already received the first positive indications of cognitive progress from the students who participated in it. The systematic analysis and presentation of the results of the evaluation tools used will soon be presented in a subsequent publication (Stavropoulos, Lavidas & Koliopoulos, 2019).

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