COGNITIVE EVALUATION OF A TECHNOLOGY-BASED LEARNING ENVIRONMENT FOR SCIENTIFIC EDUCATION

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ABSTRACT

Computer equipment and a technology based environment intended for education and training using new communication and information technologies (ICTs) mofify the context of teaching and learning. We present a study concerning the learning of physics (mechanics) using the 'MODELLINGSPACE' technology based learning environment which allows pupils to create models. It is an open environment, which offers the possibility of working on entities (representing objects) and on their properties (representing concepts). Relations of a qualitative nature, semi-quantitative or quantitative, can connect the latter. From the analysis of answers collected from secondary school students, in France, we show that the use of the software can facilitate the comparisons between aspects of reality, their conceptualisation and their symbolic notations, provided that it intervenes jointly with the concrete realization of experiments.

KEYWORDS

Experimentation, learning, physical sciences, representation, modelling, handling of symbols, technology based learning environment.

INTRODUCTION

The design of teaching tools which use new communication and information technologies (ICTs) contributes to the modification of the contexts of "teaching and learning " (Vosniadou et al., 1994). Indeed, while seeking to exploit the functionalities of the ICTs (diversification of information sources - written, visual and sound, multiplicities of representation forms, access to libraries and databases, possibility of creating discussion forums, of consulting experts, etc), the designers of educational software try to produce tools which imply other forms of work and other modes of regulation of the activities of learning. The variety of tasks with which the pupils are confronted leads to a diversification of the mental activities that are required of them. The designers are generally concerned with allowing learners to work in an autonomous way, and at their own pace. To learn how to learn, to develop higher cognitive capabilities, to facilitate and optimise learning (Switzer, Callahan & Quinn, 1999), to encourage the creation of knowledge (Komis and Michaelides, 1996). It is for these purposes that ICTs are designed. Their use is intended to allow the individualization of teaching. But what has happened in reality? In fact, a technology based learning environment exploits only part of the functionalities that the ICTs allow. The reasons for this are obvious : the limits of the cognitive capabilities of students. In the process of learning, the student's cognitive activity(seizure and coding of information, inference, reasoning, etc.) requires the implementation of multiple controls which mobilize the working memory (Legros & Crinon, 2002). The learner, if the environment is too complex, is not capable of managing several tasks. It is thus necessary to conduct studies which makes it possible to evaluate what a technology based learning environment really offers in the cognitive plan, by considering the whole of the didactic system (pupils, professors and tools) (Chaptal, 1999). Indeed, research on the effectiveness of the ICTs is far from unanimous in showing their superiority compared to traditional practices (Kulik, 1994, Chaptal, 1999, Wenglinsky, 1998).

The goal of this paper is to present a new technology based learning environment directed towards the teaching of Sciences. Basing ourselves on the analysis of the functionalities which seems to us innovative in this category of learning environment, we will investigate the uses which the pupils can make of them.

MODELLINGSPACE

ModellingSpace is a technology based learning environment, currently in the state of prototype (Dimitracopoulou et al., 1999; Komis et al., 2001),which is designed to familiarize pupils with the steps of modelling. Using this learning environment, the pupils can build models of the evolution of physical, biological, economical systems, etc. Concretely, the user of the learning environment determines the constitutive entities of the system in which he is interested and the descriptors of these entities. He proposes then relations between these possible descriptors to account for the evolution of the system. An example of a simple physical system is that which connects a pipe equipped with a tap to a barrel. Then it is a question of determining the relation, which accounts for the variation of the speed of filling the barrel.

The interest of this technology based learning environment is that it makes it allows pupils to handle various semiotic systems, and to express the entities and their relations. It is possible to understand the compatibility or the incompatibility of the relational expressions by comparing the transformations of the entities which are represented in a figurative way by dynamic images and which are associated with various expressions of the relations. We may exploit the mapping between various ways of representing the relations: graphic coding with arrows of variable size (↑↑ which means the covariation of two descriptors), logical, mathematical expression, a graph, and a table of measurements. ModellingSpace (Komis et al., 1998; Politis et al., 2001). Thus the pupils can connect various symbolic notations of relations between variables and at the same time, we suggest processes of translation between the various semiotic systems (language, semi-quantitative relations, etc). This functionality appears to be very important in the case of scientific learning, which requires the apprehension of formal relationships, which are very difficult for pupils (Cuoco, 1994; Kaput, 1987; Goldin, 1987; Janvier, 1987; Lesh et al., 1987; Moschkovich et al., 1993; Monk, 1992). Indeed, it seems now established that the construction of a new symbolic systems for the pupils proceeds cognitively out of comparison of familiar representations and new representations (Duval, 1988; Weil-Barais & Lemeignan, 1989; Weil-Barais & Lemeignan, 1990; Weil-Barais 1990; Lemeignan and Weil-Barais, 1993). We should remember that the control of the meanings that the various semiotic systems, invented by different cultures to express relations between entities constitutes a fundamental issue of scientific education. Without the knowledge of these semiotic systems, there is no possible science. The process of translation of the relations between the variables describing the entities which the software allows thus appears essential from the point of view of the learning of science.

DESCRIPTION OF THE STUDY

Hypothesis

We start from the hypothesis that the process of translation between representation systems allow students to 1) learn the meanings of symbols, which at the beginning may be opaque to them; 2) familiarise themselves with symbolic systems; 3) understand them; and 4) help them choose the most pertinent formal systems.

Objectives

If the a priori analysis of the software is right, we can expect that the pupils who use it will have a different approach to the physical systems with which they are confronted. Used to formalize the constitutive entities of the systems in terms of properties and relations between dimensions, they should account for the transformations of the physical systems in a different way than the pupils who have only practical experiences of the physical systems.

The study was conducted in connection with a traditional situation studied in mechanics: the displacement of a vehicle on an inclined plan.

Problem

The problem suggested to the pupils is the following: " a car without engine runs on a road which can have a more or less acute slope". A series of questions are posed to the pupils aiming at leading them to be interested in the relations between speed and mass, speed and angle of the road, speed and type of the road, speed and time of displacement.

Example of the questions:

- Could you make it so that the car placed on the paper surface is made to move without you having to touch it?
- Which are the factors that have an effect on the speed of the car?
- On which surface (concrete, frozen, etc.) does the car move faster? Explain your answer.
- A car rolls on an inclined road slope. Imagine that a second car, larger this time, moves on the same road. Which car will go down faster? Explain your answer.
- Can you describe the state relationship between the speed of the vehicle and the duration of displacement?

The pupils have either a set of objects (cars and supports), or the technology based learning environment.

Description of ModellingSpace images

The screen of the computer shows the image of a car represented as an entity. We can describe it by its mass and speed (called ‘properties’ in ModellingSpace). The mass and the speed of the car can be modified. The modification of the mass is represented by three different sizes of cars. The modification of the speed is represented by an increase of the shade beyond the car as we see on the images reproduced in figure 1.

Figure 1. The representation of the modification of mass and speed

The other image (entity) represents a road which has two properties: angle and type of road (that corresponds for us to the coefficient of friction, but we did not use this denomination because it is unknown to the secondary students to whom this task is addressed). The angle can have various values: the road can be horizontal or more or less tilted. The road surface can be icy, or wet, or made out of concrete or be a dirty road. (These images correspond to our representation of the coefficient of friction which is minimal (zero) in the case of icy road, maximum for the dirty road, the two other roads (wet and concrete) correspond to intermediate values, in the following order of the friction coefficient (figure 2).

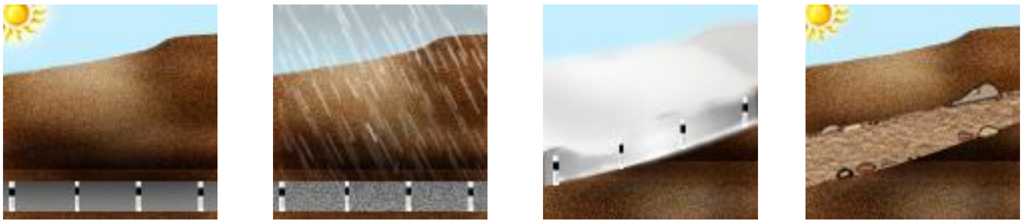

Figure 2. Representations for the modification of coefficient of friction and the angle

On the screen, the image of a clock also appears, representing the time necessary for the displacement of the car. Time has the status of the independent variable compared to the other properties, which are the dependent variables.

Method

We compared the descriptions and manipulations made by the pupils when they had material objects (various plastic cars and various plane surfaces: paper, plastic …) to carry out the experiments and when they uses the ModellingSpace which makes possible to model and simulate symbolically the experiments. In so far as we can make the assumption that working on the objects and symbolic notations can have reciprocal effects, we counterbalanced the order of the conditions: a group of pupils worked initially with the technology based learning environment, then with the objects, the other group made the reverse (objects, then learning environment).

We conducted interviews with 26 pupils of college attending the classes of 8th (13-14 years old) and 9th (14 - 15 years old) located in the Paris area. The duration of each interview was 15 - 20 minutes. The pupils had volunteered to participate.

RESULTS

In the framework of this communication, we will have only the results concerning the pupils' understanding of the relation between the angle of the surface and the speed of the car.

When the experiments are carried out with the computer

After the experimenter has successively set up, using the tools described previously (entities and properties), the various relations (between mass and speed, type of the road and speed, speed and angle), pupils are invited to look on the screen at the dynamic images which correspond to the formalization. The following question was put: "according to what you saw, can you say which is the relation between the speed of the vehicle and the angle of the inclined road? ". The second time they had to choose from a of iconic representations of relations, the one which was most appropriate and also justify their answer.

<u>Relation between the speed of the vehicle and the angle of the inclined road</u>

The answers are distributed in the following way:

- 20 pupils said that the car goes faster giving various explanations,
- 4 said that the car goes slower,
- 2 gave no conclusion on the speed but about the state of the road or evoke the acceleration.

These answers reveal that spontaneously the pupils focus themselves only on one property (mainly speed), sometimes making a mistake in the interpretation of the direction of the change in speed (4 out of 26 pupils). They do not express the covariation between the increase of the slope and that of speed.

<u>Symbolic expression of the relation</u>

When we ask them to choose the most appropriate symbolic expression, the majority of pupils (17/26) choose the relation which expresses the covariation (↑↑). However other answers appear, often multiple (see table 1)

Table 1. The relation between the speed of the vehicle and the slope of the plan

	1st relation (↑↑)	**2nd relation** (↑↓)	**2nd 3rd relations** (↑↓) (↑-)	**1st 2nd 3rd relations** (↑↑)(↑↓) (↑-)	**4th relation** (↑↑)	**No relation**	**Total**
8th (13-14 years)	8	3	1	0	0	0	12
9rd (14 – 15 years)	9	2	0	1	1	1	14
Total	17	5	1	1	1	1	26

Justifications

The verbal justifications of the pupils are of different nature. They are discussed below and their distribution is presented in table 2.

- Expressions of a co variation (COVA) or a contra-variation (CONTRA)
- For example, a 13-year old pupil said: « …the slope increases and the car goes more quickly » (COVA). The pupils who chose the relation of covariation use suitable linguistic forms. The pupils who did not produce these relational expressions chose , instead semi-quantitatives relations erroneous or multiple, thus demonstrating their uncertainty.
- Mistaken answers were also given due to the fact that the dynamic images were not perceived in the way the originators of these images expected it. For example, a 14-year old pupil mentioned: « The more the slope increases, the more the speed of the car decreases ». Another pupil explained that « the more the car goes down, the more the road goes up ». Another 14-year old considered that « The more the inclination of the road …the more the car goes quickly » (CONTRA). Thus, these pupils were led to choose the 2nd relation.
- Such observations stress the importance of the understanding of the relations in natural language. The assumption that one can advance is that if the pupil is not able to understand the transformations relationally, in natural language, s/he is unable to do it with formal systems.
- Evocation of properties (POBJ)
- This is the case when the pupil evokes only one of the properties of the object, for example a 13-year old pupil said: «… it is faster » and he chose the 1st relation.
- Conceptualisation (CNST)
- Some pupils conceptualised the situation in physical terms of sizes. For example, a 13-year old pupil explained: «The car accelerates when it is on a slope…» and he chose the 1st relation.
- Sequential description (DESC)
- Certain pupils described the movement when the car goes up and when it goes down, as if the two elements of the image and of the icon represented successive states of the movement. For example a 14-year old pupil affirmed: «when the car goes down, it goes more quickly and when it goes up, it goes less quickly ». Another indicated that « the road goes up (↑) and the car slows down (↓), remains at the same point » and there he chose the second relation (↑↓). We found the strategy of sequential reading of the images and icons already described by other authors was an obstacle for understanding the variational approach of the relations (Baillé & Maury, 1993; Janvier, 1998).
- The comparison of the given justifications according to whether the software was used before or after the experimentation with the objects (see Table 2) underlines that the use of the variational expressions is more important when the pupils have experimented with the objects. The sequential treatment of the images and the icons is not very frequent (4 pupils out of 26) but it concerns particuliarly the pupils who used the software without doing any practical activities previously.
- This result shows that only half of the pupils could adequately process the data presented on the screen of the computer and that they were more numerous if they had previously handled the objects represented on the screen of the computer.

Table 2. Justifications of the choice of the relational semi-quantitative expressions between the slope and speed

SCOOL LEVEL / Categories	*ModelsCreator (used first)*		*ModelsCreator (used second)*		
	8th (13-14 years)	**9rd (14 – 15 years)**	**8th (13-14 years)**	**9rd (14 – 15 years)**	**Nb pupils**
Co-variation (COVA)	1	2	4	6	13
Contra-variation (CONTRA)	1	1	0	1	3
Properties of the objects (POBJ)	0	3	2	0	5
Conceptualisation of the situation (CNST)	1	1	1	0	3
Sequential description (DESC)	3	0	0	1	4
Other answers	1	1	0	1	3
Number of pupils	6	7	6	7	26[1]

When 'real' experiments are carried out

When the pupils carried out the experiment, the following question was put to them: When the slope of the plan increases, what happens with speed? (It does not change, it increases, it decreases). Explain your answer.

Predictions concerning speed

All the pupils, except one, answered that when the slope of the plan increases, speed increases too. Only one pupil said that it does not change: « *Bah! That does not change* ».

Explanation of the relation between the slope and speed

The arguments advanced by the pupils were of different natures. They are discussed hereafter and their distribution is presented in table 3.

- Relation of covariation (COVA) between the slope and speed (more…more). For example, a 14-year old pupil affirmed: « The more the slope increases, the more the speed, while going down, will also increase » or of contra-variation (CONTRA): «The more the slope is steep, the more… e, less the car is held back ».
- Evocation of an object property (the car or the surface) accompanied with a comparative term of the « steeper, larger, stronger » (POBJ). For example, a 13 year old pupil answered: « It (speed) increases because it is steeper there... ».
- Putting a correspondence between the physical situation and its representation on the screen (CORR). For example, a 14-year old pupil who had already carried out the experiment with the software answered: « it … returns to the same question ».
- Mobilization of a physical concept like acceleration, push (CNST). For examples: «Bah, the car, it will go always downwards », « The car goes more quickly because it has more time to accelerate. There is more space to accelerate».

[1] The total of this column is higher than the total number of pupils because a pupil can give several justifications.

- Notation of the type: it will go more quickly, the wheels turn more quickly etc. (NOTI). For example, « It increases because the wheels… e… that involve … the wheels turn more quickly » (a 14-year old pupil).
- Expression of a feeling that it is normal or logical as « it is normal, logical or it is obvious » (OBVI). For example, a 13-year old pupil said: « I do not know, it is obvious, that appears so obvious ».

Table 3. Explanations of the relation between the slope and speed, if the pupils carry out the experiments with the material

SCHOOL LEVEL / **Categories**	***Experimentation with the objects after use of ModelsCreator***		***Experimentation with the objects before use of ModelsCreator***		
	8th (13-14 years)[e]	**9rd (14 – 15 years)**	**8th (13-14 years)**	**9rd (14 – 15 years)**	**Nb Pupils**
Covariation (COVA)	0	2	0	2	4
Contra-variation (CONTRA)	0	0	1	0	1
Properties of the objects (POBJ)	1	1	0	2	4
Put in correspondence (CORR)	2	0	0	0	2
Physical concept (CNST)	0	1	0	0	1
Notation (NOTI)	1	2	5	5	13
Obvious (OBVI)	1	0	1	0	2
Other answers	0	1	1	0	2
No explanation (NEXPL)	3	2	1	1	7
Number of pupils	6	7	6	7	26

Half of the pupils (13 out of 26) justified by observation their prediction relating to speed according to the slope of the plane on which the car moves. This concerned in particular the pupils who had experimented with the objects. Those, who first used ModellingSpace did not seem to understand the experiments in a singular way. They do not put in correspondence spontaneously equate the experiment with what they before saw the screen.

CONCLUSION AND PROSPECT

If we compare the advanced explanations of the pupils according to whether they experimented with the objects and the technology based learning environment, it appears that the variational relational approach is much more frequent with the learning environment than with the objects (13 out of 26 in the first case, against 4 out of 26 in the second case). However, this approach appears especially marked when the pupils had experimented with the objects before the use of the technology based learning environment. These results, obtained with a small number of pupils, would need to be consolidated. Indeed, they draw attention to the cognitive benefit of the use of the learning environment if it is preceded by an experimental activity with the relevant objects.

The results obtained support the hypothesis that ModellingSpace constitutes a good tool to help pupils to understand the transformations of the situations into relational terms. However, they draw attention to the need for practical activities using the objects and the questions about them.

The limitation of the work presented is due to the conditions of data collection: individual interviews where we avoided bringing in other information than that provided by the activities themselves, with the objects or the software. Future studies with small groups of pupils will make it possible to specify the effects of the interactions between pupils.

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