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Contemporary Scientific Concepts in Primary Schools: A Test Case on the concept of Systems.

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Abstract. *One crucial parameter of the effectiveness of Science and Technology teaching in schools, especially in Primary schools is the syllabus. The modern approach and contemporary scientific concepts are missing, one reason quoted to this being that the children cannot understand them. In this work we test this excuse using the concept of systems. The results from a test teaching in a primary school show that, properly taught, complex concepts may be well understood by children.*

Keywords. Systems, Science Teaching.

1. Introduction

The importance of Literacy in Science and Technology (STL) as a basic parameter for the welfare of modern, technology dependent societies has been repeatedly stressed. The effective teaching of Science is an important parameter towards this end and many works have been appeared, mostly on a constructivist approach some also focused on the scientific inquiry approach [1]. However, to our opinion, a crucial parameter towards an effective Science and Technology Literacy, the syllabus content, seems to be ignored. Not only contemporary concepts and modern scientific achievements like systems and chaos, fuzzy logic, etc, are missing from the school Science syllabus but also the century or more old concepts of the theory of relativity and quantum mechanics [2], stochastic processes, etc. only superficially make a hit to the school program [1]. Possible (excuses and) causes of may be:

a. The general trend of Science achievements paths into the school program is a "top-down" process; a new research concept finds its way to post-graduate studies, sometime later to undergraduate studies, then to high school, to medium school and, hopefully, into primary school. Mostly, this is done as an add-on separate theme of a technical descriptive nature without any real integration into the syllabus, a very detrimental way towards the understanding of Science, especially if a new apprehensive of the natural phenomena is introduced. This may explain the absence from the school syllabus of the (very) new scientific achievements.

b. Teachers in schools and the influencing other educators having lost their contact with recent developments in the field either they are not aware or they do not understand achievements they had not been taught during their studies. This is a very serious problem and it may explain the absence from the school syllabus of themes like the theory of relativity or quantum mechanics. This cause together with the artificial add-on nature of the syllabus build-up referred to in **a.** above, may provide an alternative explanation to the general belief that "children think in an Aristotelian way", quite often supported with field data [3].

c. Children are not able to understand new concepts which scientists have to spend a lot of time to understand. This seems to be a "self-evident" statement but it bears no factual support. On the contrary there are field data indicating that what is perceived as a difficult subject for the students it really reflects difficulties of understanding on the part of the teachers.

In this work we test this last cause (or excuse). To this end we have chosen the concept of systems. This choice was made on the following reasoning:

d. The concept was more familiar to the teacher and consequently any possible effect of **b.** above was minimized.

e. The word system is a commonly used word in many expressions of everyday life; consequently we expect many preconceptions from the students. As a result, a successful teaching intervention will show clearly, even with a relatively small sample.

f. Characteristics of systems, e.g. relations between different parts of a system are included as factual knowledge in the school syllabus, for example (some) relations between constituents of an ecosystem. Consequently the students, who, in a Piagetian context, have not as yet reached the stage of formal logic, are not faced with a concept totally abstract to them.

2. Methodology

Students of the 5th grade (11 years of age) of the 2nd primary school of Souda bay at the prefecture of Chania were used. All field activities were effected during school year 2004-05 by N. Kountourakis from the authors of this work, who was also the teacher of the students. Souda with a population of 8.000 is located about 6km from the city of Chania; in the area operate 3 primary schools, one middle school, one high school and a higher vocational school for merchant marine. Souda is a major naval and merchant port. In its area there are also flour and cattle feed industry. Near the school of study a small lake ecosystem with herons and other aquatic birds is located.

The whole work was organized in the following steps:

Step 1: A questionnaire with 4 parts (A, B, C and D) was created:

A. Questions related to their profile (sex, overall mark during the previous year, education and occupation of the father and of the mother),

B. Questions related to their ideas on the concept of a System. The specific questions and their type were chosen so as to trace different levels of understanding and include:
- Have you heard the word system (closed question with choices yes, no, do not know)
- Could you write some expressions you have hard including this word (open question)
- Give some examples of systems (open question)
- What do you think a System is (open question)

C. Which of the following words do you relate with the notion of system? Words used: clock, stereo sound system, refrigerator, water, reading, lemon tree, human being, soccer team, state (country), PROPO (a game of chance to predict the results of soccer games), wood (of trees). Choices for each word: it relates, it does not relate (to the notion of system). Each of these questions was chosen either because it is used in everyday expressions together with the word system or because they may be considered as systems according to the school syllabus (see **f.** above). This question is considered useful to the interpretation of the findings on the previous questions.

D. To trace their understanding on the interrelations between parts of a system, the students were presented with an island as a closed (eco)system with cultivations, wood of different trees, and a variety of flora and fauna. Then they were presented with different scenarios and asked what the influence of each scenario would be on soil, on flora, on mice, on wolves, on humans (choices for each system constituent: a/influenced, b/not influenced). Again, related references may be found dispersed in the school syllabus. The scenarios used are:
- The soil is polluted with chemicals,
- A fire destroys the cultivations and the wood,
- A disease eliminates almost all the deer.
- The Humans eliminate all wolves.
- The Humans abandon the island.

Step 2: A test run with 4 students of the 6th grade (age 12) followed by interviews was effected in order to check the validity of the questionnaire and get some insight from its application especially on matters of clarity of the specific phrasing used.

Step 3: Twenty two questionnaires were filled by (all the) students of the 5th grade (age 11) of the school (13 girls, 9 boys). An open discussion followed to get some insight on the reasoning behind the specific answers given.

Step 4: Based on the filled questionnaires and the discussion followed, a teaching intervention on the concept of Systems was organized along two axes:
- The concept of a 'System', as a complex with interrelated parts.

- The 'systemic thinking' as the (extent of) interrelations between the different parts of a system. The aim was to advance further from the simple direct interrelations with reasoning of the form: constituent x influences constituent y, constituent y influences constituent z, consequently constituent x influences also constituent z (indirect influence).

Note. We must stress that in a Piagetian context, the students in this age are mostly in the concrete (and towards the formal) operational stage able (mostly) to one parameter (direct, one to one) relations. Consequently, the expectations here should be limited.

The teaching, based on constructivism, was done one month after the collection of the questionnaires in two parts one week apart. It was followed by homework during the Christmas – New Year recess.

Step 5: One month after the teaching, a new questionnaire was given to the same students. Its structure was similar to the first one with the following differentiations (compare with **C** and **D** referred to previously):

Part C: For every one of the following words explain if it may denote a system or not. Words included were: clock, water, reading, human being, soccer team, state (country), TV set, Car, nettle (a plant in abundance in the area), brick, lake, cat, a pack of wolves, and a village.

Part D: Students were presented with two systems and different scenarios and asked to tell what will happen on different scenarios and why. The two systems were:

- A lake with aquatic flora and fauna, turtles, herons, fishermen and hunters. Scenarios were: toxic chemicals are discharged into the lake, a large hunter fish is introduced into the lake by the fishermen, the authorities ban fishing and hunting in the lake.
- In our small city Souda (see the first paragraph of this section) what would be the effect on the grocers, the 'rent a room' owners, the school-students, the police force, and the school-teachers in the following scenarios: a/ the two industries are shut down, b/ a (new) University is established in the city.

The first case corresponds to the 'island' system of the pre-test. The second case is a more complex system on a concept (our city) which is scarcely considered in common life, even less in school teaching, as a system. It was put to test if the teaching intervention was successful on the understanding of systems and interrelations between their parts. In both cases, this time students were asked also to explain their answers, a step which in the pre-test it was replaced with the open discussion of the answers given.

3. Results

The data collected are still analyzed; however prominent conclusions are already emerging and we present them in brief.

General comments.

- The profile of the sample is representative of the Greek school students.
- Although the questionnaire was very careful phrased, some questions were not clearly apprehended by some of the students. For example, influence was mostly understood as diminishing (in numbers) or as a negative (on values) notion despite the oral explanations.
- Similarly a result that was considered as a wishful result it was not conceived as an interrelation. For example in the second system of Part D above, although many students recognize that the income of the grocers or the 'rent a room' owners will probably be increased, they do not consider it as an 'influence' because this is a desirable (positive) outcome.
- These problems restate a fact known also in other specific on this issue studies that in this age many of the students do not master the written language in full. Consequently, although the difficulties on the correct understanding were not to a significant extent, the interviews (and/or the open explanations) seem a necessary compliment to the questionnaire.

On the concept of System.

From the pre-test it seems that the majority of the school students perceive the notion of system as something repetitive or something planned or at least involving human action. For example:

- 'Reading' was considered as a system by 17 of the 22 students because 'it has to be planned systematically'.
- 'Water' was quoted as system by 14 out of the 22 because it was related to the house water supply or to the irrigation system or because of its repetitive cycle

of evaporation-clouds-rain-sea, rivers and lakes (a subject they already have been taught in the previous years). None quoted it because it is composed by hydrogen and oxygen, a subject they already have been taught

This inference is enhanced by the examination of the response to other questions. So, although the lemon tree and the human person have both been taught as complexes with different interrelated parts, only 6 out of the 22 perceive the lemon tree as system, in comparison with the 18 out of the 22 quoting the human body as a system. Even more, only 4 out of the 22 related the wood tree as a system despite the obvious multitude of trees and their teaching of the wood as a specific ecosystem.

However only 4 of the 18 related their answer to the different parts of the human body, the rest justifying their answers along the lines '… humans act, plan their actions'. The lemon tree was related as a system not because it is a complex but because its repetitive cycle of flowers-lemons. Those who did not related the wood tree and/or the lemon tree as a system justified there choice because '… the lemon tree and the wood tree do not act on purpose …'. The students who related as a system the lemon tree but not the wood explained: '… lemon tree yes because every year it produces lemons we eat while the wood no because we only cut wood…' and '… the wood no because it is trees sprang out by chance …'.

The results of **Step 5** (the post-test) show a remarkable improvement. More than one month after the teaching intervention 16 out of the 21 (one student was absent) not only are able to state a correct (working) definition of 'system' but they also explain their associations to the notion of a 'System' as a complex of interrelated parts. On the other hand, only 11 out of the 21quote (on question 1) also at least one of the examples they gave in the pre-test as a 'system', a remarkable improvement although it still indicates 'resisting ideas'. Also, 20 out of the 21 consider the human body as a 'system' because it has constituent parts. This result may not be due to the memory of the specific on this discussion because the 21st refused the human body as a system '… because it is a whole not composed of parts'. Similarly the cat was considered as a system by 16 out of the 21. Of the rest 5 remarkable is one contempting explanation '…when the cat suffers who is affected?'

On the systemic thinking

The data from the pre-test indicate the validity of Note referred in **Step 4.** earlier. Students' thinking is limited to direct, one parameter relations. For example, on the scenario of chemical pollution of the soil, of the 22 students, 21, 10, 11 stated an influence on the plants, the mice and the wolves correspondingly. Some explanations on the non influence: '… mice are used to polluted environment e.g. the drainage system', '..wolves do not lay on the soil..', '… mice and wolves do not eat plants …', etc.

Similarly, to the scenario of fire, the corresponding quoted relations were 22, 11 and 16. Some explanations on the non influence: '… mice and wolves can move away' and other similar to the previous ones.

To the scenario of deer elimination, the corresponding numbers were 5, 4 and 17. Explanations for the non-influence include: '… plants are different from deer and they will not catch the disease..' (limitation to one – the more prominent - factor), '… wolves can smell the sick deer and they will not eat them…'.

To the scenario of the elimination of wolves the corresponding answers were 3, 2, and 20. Some explanations: '… wolves do not eat plants (so the plants will not be affected)', '… plants may increase a little because the wolves will no more step on them'.

It is evident the one parameter and the direct only relations thinking of the students. This conclusion is enhanced by the observation that during the discussion, on commenting the question what will happen to the deer if the wolves are eliminated the students stated that they will increase so they will eat more plants which will start diminishing, however they had not related this in the test.

Interesting is also the explanations to the scenario 'the Humans abandon the island'. There will be influence to the plants, the mice and the wolves quoted 18, 9 and 10 (out of the 22) students. Some explanations: '.. the plants will diminish because the area will remain uncultivated… the plants will not be watered so they will run dry and die..', mice will be affected because they are fed on the food remnants of Humans', mice and wolves will not be affected because they will feed on other means'. It is remarkable that mostly the (one parameter – one way) thinking is around human activities only and focused on food. May be because the most extensively taught relation (and almost all of the

examples given) on the ecosystems is focused on food. Also, in the previous 4 years, within the context of the course 'Study of the Environment', they are taught repeatedly and almost exclusively the Environment in relation to human activities and needs only.

The data on the post-test are still being analysed, especially in comparison with the pre-test data. The analysis is complicated more because of:

- The reason stated as a Note in **Step 4** previously,
- The small sample and the limited teaching intervention for an, otherwise, complex subject.

Preliminary results show that, in general, there is an improvement towards systemic thinking but it is not clear if this is consistent and systematic or circumstantial. However, at least 5 students (>20%) show a clear evidence of advance to a two step indirect relation similar to the example given earlier as objective of this teaching intervention. This rather high figure indicates that a more thoroughly planned teaching intervention may have still better results.

Conclusions

Our small scale study shows that:

- The concept of 'system' is well within the abilities of the 5th grade school students.
- The situation with the development of systemic thinking is not so clear. Based on the fact that the 5th grade school students, in a Piagetian context, are advancing from the concrete to the formal operational stage, we hypothesize, that systemic thinking is also within their abilities and that a more thoroughly planned teaching intervention may provide more evidence to this. The fact that of the 5 students who showed a clear evidence of advance towards a systemic thinking the 4 were girls (who mature earlier) combined with Vygotsky's [4] context of the Zone of Proximal Development reinforces our choice.

In any case our basic objective that we should put under the test of empirical evidence the general belief that 'children are not able to understand new concepts which scientists have spent a lot of time to understand' has been validated, at least partially.

4. Notes and References

[1] See a review in P. G. Michaelides, "State of the Art of Science Teaching" invited lecture, 1st International Conference on Hands on Science: Teaching and Learning Science in the XXI Century, 5-9 July 2004, Ljubljana, Slovenia, proceedings, pp. 11-17

[2] George Kalkanis 'Which (and How) Science and Technology Education for Future Citizens?', pp. 199-214 of Vol. II of the proceedings of the University of Cyprus, '1st IOSTE Symposium in Southern Europe – Science and Technology Education: Preparing Future Citizens', Paralimni-Cyprus 29/4-2/5 2001.

[3] Similarly, it was found that Greek school students in Greece, German, Greek and other nationalities school students in Germany share the same ideas on Heat, inconsistent with their teaching, despite their different social origin. These were the ideas based on the concept of the 'caloric fluid' very prominent some centuries ago and considered as an example of Aristotelian thinking. A closer investigation showed that these conceptions were most probably originated from the non rigorous and simplistic phrasing of the textbooks (G. Vlachos, Investigations of the Ideas of Greek and German school students about Heat and Effect of Teaching, PhD Dissertation, Rethimno, Crete 2002- in Greek).

[4] Lev Semyonovich Vygotsky (November 17(5), 1896—June 11, 1934). Born in Orsha, Belarus now. Studied Law and Medicine in the Moscow University. He died of tuberculosis. His first works were on Literature and Poetry. An essay he wrote at the age of 18 on Shakespeare's Hamlet was used later to his writings on Psychology. In contrast with Piaget his work's context was that intellectual development is not a process of the individual but a function of the interaction with the society. His works were banned for long time and rediscovered by the so called West at the 60's.