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Full Length Research Paper

The impact of alternative science education methodologies on the motivation and acquisition of scientific concepts

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Abstract

Fully aware of the increasing importance of active and experimental learning, this study has been conducted in Portugal between 2007 and 2008 and was the first of this kind to ever be conducted in this country. Thirty eight students of the school E.B. 2, 3 D. Maria II (middle school) participated in the extra-curricular activity entitled "Scientists for a Day", previous developed by the Life and Health Science Research Institute/School of Health Science (ICVS/ECS), University of Minho. This activity realized in the School E.B. 2, 3 D. Maria II and organized by teachers of the same School consisted in a set of laboratory activities subdivided into four experimental stations, namely: 1st Station – "Extracting banana DNA"; 2nd Station – "Acid/Base", 3rd Station – "Observation of chicken embryos" and 4th Station – "Five Senses". The general objectives of this activity were to stimulate the pleasure of knowledge, encourage critical views, heighten the interest in science, motivate students towards experimental work and demystify the idea of what a Scientist is. In an effort to validate this activity and evaluate what they have learned, the students were asked to answer a questionnaire before and immediately after this activity. In this study we observed a clear correlation between the use of active and experimental learning activities, and an increase in scientific knowledge.

Keywords: Middle School Sciences, Laboratory Science, Extra-curricular activities, Alternative science education, Research experiences.

INTRODUCTION

Science and Technology are present in all aspects of everyday life, although its presence may not always be obvious. Likewise, the role of Science and Technology is clearly established in the "Portuguese School Curriculum for Basic Cycles 1, 2 and 3" (Departamento da Educação Básica (DEB), 2001).

As far as Biology is concerned, its importance has been particularly recognized due to its major influence in the population's quality of life and in the organization of the societies. We often try to find answers in recent discoveries in Biology to solve the problems that affect our civilization. New problems generate diverse alternatives which demand technological/scientific, political, social and ethical decisions. In that sense, it is necessary to help students achieve a level of scientific literacy. In this context, it is important to adopt active learning methodologies which are able to motivate students, namely, experimental teaching.

Today's society demands a reconsideration of strategic methodologies in order to replace traditional lecture with pedagogical practices which help create competent individuals capable of reconstructing knowledge and, therefore, using it to improve their quality of life (Borges and Lima, 2007). Students show a vast experience in passive learning environments, however, it is expected of them to also demonstrate active learning knowledge and participate as well. In this scenario, it is the teacher's role to help the learner to learn, and the students' role to be active and to take responsibility for their own learning (Michael and Modell, 2003). Discussion motivates students for further study, develops "thinking skills" (Mckeachie, 1972) and also increases the students' attention span, in comparison to traditional lecture.

Fully aware of the increasing importance of learning in active environments, we carried out in the *School D. Maria II* (a middle-school for Basic Cycles 2 and 3) of Vila Nova de Famalicão, a scientific and pedagogical activity entitled "Scientists for a Day", which had been previously developed by *Life and Health Science Research Institute/School of Health Science* (ICVS/ECS), University of Minho, Portugal (Azevedo *et al*., 2011).

This activity represents a specific proposal to help teachers develop the core elements of active learning, specifically, the ones that aim to develop, experimental activities, interpretation skills, synthesis and critical analysis.

The general objectives of this activity were similar of the described by Azevedo *et al*., 2011. To validate this activity and evaluate what they had learned, the students were asked to answer a questionnaire before and after this activity (Pre-test and Post-test).

Material and methods

This study was conducted between 2007 and 2008, and it is a pioneer study realized in Portugal. A convenience sample was used.

The assessed group consisted of 38 students of same team between the ages of 12 and 15, of the 7th grade of the school *E. B. 2, 3 D. Maria II*, located in the municipality of Vila Nova de Famalicão, district of Braga, Portugal. The normal age for this grade is 12-13 years; however some students have been retained.

Data collection was processed through a questionnaire, which included 86% of multiple choice questions and 14% of open answer questions (Pre-test). This evaluation instrument was developed by Azevedo *et al*., 2011, was applied in regular classes and was pre-tested on 10 students (see Table 1 and 2). Student participation was voluntary and anonymous and had a limit of 45 minutes for its conclusion. The level of participation reached 100% since students were persuaded of the importance of this study.

This evaluation instrument was designed to test the students' knowledge regarding several areas such as: heredity, acid/basic concept, embryonic development and sensory perception (see Table 1 and 2). The same questionnaire was applied to the students before (Pre-Test; control) and after the experimental activity took place (Post-test).

Afterward the activity developed at (ICVS/ECS), University of Minho it was implemented in the school *E. B. 2, 3 D. Maria II*. All the students of the 7th grade participated and executed all the experiments suggested (Azevedo *et al*., 2011). This activity was careful planned and organized for the Natural Science teachers of 3º cycle from this school, and the students that previously had participate in the activity "Scientists for a Day" in the (ICVS/ECS) (Azevedo *et al*., 2011). The explanation of all the experiments was made by the students with the teacher collaboration. All the doubts were analyzed in detail promoting the interaction between student/student and teacher/student. When is possible and according the students answers, these were stimulated to encourage reflexion.

In order to carefully validate this activity, the same questionnaire (Post-test) was answered by the 38 students that had answered the Pre-test (control situation), in the same day of the experimental activities (see Table 1 and 2). The students were previously advised that after the experimental activities they will be evaluated; nevertheless they didn't know the evaluation instrument.

The data was converted in percentage and statistically treated using a statistic software SPSS (Versão 14.0. SPSS Inc., Chicago, IL, USA). In order to identify significant statistical differences, the data was analyzed using Pearson's Chi-square test ($\chi2$) and the values were considered statistically different when $p<0.05$.

Results

The activity "Scientists for a Day", according Azevedo *et al*., 2011 consisted in a set of laboratory activities subdivided in four experimental stations, namely: 1st Station "Extracting DNA from a banana", 2nd Station "Acid/Base", 3rd Station "Observation of chicken embryos" and 4th Station – "Five Senses". The objectives and methodologies for all the stations are the same described by Azevedo *et al*., 2011.

Table 1. Correct answers of students (%) concerning the stations 1-4 and some general aspects ($p \leq 0.05$)

Questions		% Correct answers		% Increase in correct answers	*p* value
		Pre-test (R.PRE)	Post-test (R.POS)	Δ (R.POS-R.PRE)	
Extracting DNA from a banana	What is the importance of DNA?	40	77	37	$p < 0.001$
	Contain DNA:				
	tulip	41	97	56	$p < 0.001$
	mold	18	50	32	$p < 0.001$
	cabbage	55	100	45	$p < 0.001$
	Is it possible to visualize DNA?	6	86	80	$p < 0.001$
	Mean	32	82	50	-
Acid/Base	Are you familiar with the acid/base concept?	60	88	28	$p = 0.026$
	Is it possible to use red cabbage as an acid/base indicator?	8	86	78	$p < 0.001$
	pH of:				
	juice	10	47	37	$p < 0.001$
	coca-cola	38	92	54	$p < 0.001$
	caustic soda	27	61	34	$p < 0.001$
	detergent	14	54	40	$p < 0.001$
	water	41	86	45	$p < 0.001$
	Mean	28	73	45	-
Observation of chicken embryos	Are there similarities between embryos of different species?	40	82	42	$p < 0.001$
	Do 3-day old chicken embryos have paws?	68	97	29	$p = 0.038$
	Does the heart of a 2-day old chicken embryo beat?	59	100	41	$p < 0.001$
	Are chicken embryos used as models in science?	50	86	36	$p = 0.009$
	Have you observed live chicken embryos?	28	94	66	$p < 0.001$
	Mean	49	92	43	-
Five senses	Are there interactions between sense organs?	25	97	72	$p < 0.001$
	Mean	25	97	72	-
General aspects	What is an experimental protocol?	8	90	82	$p < 0.001$
	Can experimental protocols be simple?	36	95	59	$p < 0.001$
	Are you able to do simple experiments at home?	11	80	69	$p < 0.001$

Table 1 contd.

	What precautions must you take in a laboratory?	48	98	50	$p<0.001$
	Who should conduct experiences?	45	72	27	$p<0.001$
	Mean	30	87	57	-

Table 2. Correct answers of students (%) concerning the stations 1, 2 and 4 (p>0.05)

Stations	**Questions**	**% Correct answers**		**% Increase in correct answers**	***p* value**
		Pre-test (R.PRE)	**Post-test (R.POS)**	**Δ (R.POS-R.PRE)**	
Extracting DNA from a banana	Contain DNA: pen	98	100	2	$p=0.341$
	turtle	98	100	2	$p=0.094$
	microorganisms	70	97	27	$p=0.182$
	ball	97	100	3	$p=0.341$
	mp3	94	100	6	$p=0.175$
	water	59	54	-5	$p=0.690$
	Mean	86	92	6	-
Acid/Base	pH of: lemon	81	84	3	$p=0.833$
	Mean	81	84	3	-
Five senses	Can there be different perceptions of the same temperature?	88	90	2	$p=0.630$
	Mean	88	90	2	-

Station I – Extracting DNA from a Banana

Data from pre-test showed that 40% of the students have knowledge about the importance of the nucleus in the cell, however this percentage increase significantly in the post-test ($p<0.001$) (Table 1). Regarding the absence /presence of DNA in different objects/living beings, (pen, turtle, microorganisms, tulip, mold, ball, mp3, water, cabbage) in the pre-test the students revealed reasonable knowledge, despite this topic is only referred in the 9th grade, however in the post-test significant improvements occurred (Table 1), with exception for water (Table 2).

In terms of DNA visibility, in the pre-test only 6% of the students answers correctly. Nevertheless in the post-test this percentage increase significantly 80% ($p<0.001$) (Table 1). Globally, we observed a significant improvement in all aspects explored in this station.

Station II – "Acid/Base"

In this station, the students tested several foods and day-to-day products, regarding its acidic, basic or neutral properties. In terms of concepts such as acid/base in the pre- and post-test respectively 60% and 88% of the students answer correctly ($p=0.026$) (Table 1). Concerning the use of red cabbage as a pH indicator, significant progresses were made after doing this activity ($p<0.001$) (Table 1).

Regarding the pH value of certain substances in the pre-test there were detected a lot of difficulties. In the post-test some difficulties persist, however significant improvements occurred (Table 1) excepting for lemon (Table 2). Globally in the pre-test we detected lack of knowledge, since this topic is teach in the 8^{th} grade, however considerable improvements occurred between the pre- and post-test. Globally, this experimental station fulfilled the proposed objectives.

Station III – Observation of chicken embryos

We point out that in the pre-test the students showed some difficulties in terms of embryo development related issues, such as : the similarities that exist between vertebrate embryos during the first stages of development; they had modest notions regarding the time it takes to develop the structures that precede the eye, ear , brain, vertebral column and the limbs in the case of the chicken embryos; and 50% of the students didn't known the importance of using chicken embryos as models (Table 1). Concerning all of these aspects in the post-test significant improvements occurred (Table 1). The correct answers obtained in the pre-test (mean 49%) were pure chance, since these topics are not dealt with throughout previous school levels.

Station IV – Five Senses

In this station, the students conducted experiences so that they would understand that the senses work and cooperate with and each other and that it is possible to "deceive the senses".
In the question regarding the interaction between sense organs, 72% of the students improved their performance between the two evaluation moments ($p<0.001$) (Table 1). In the experimental situation related to the different perceptions of the same temperature, the results of the pre-test and the post-test were similar (Table 2).

General Aspects

In addition, this study was also conducted so that the students could achieve other objectives, such as: understanding Science as a simple and effective tool for problem solving; visiting laboratory environments; conducting simple experimental protocols; encouraging the students to actively participate in the experiences and in the results' interpretation.
With this in mind, we have studied the student's knowledge regarding experimental protocols, laboratory environments, precautions in the laboratories and which kind of people can make experiments. Several difficulties were visible for all these topics in the pre-test; however, they were resolved after this activity (Table 1).
Regarding open answer questions, such as interest in one day becoming scientists 21% of the students in both evaluation moments showed interest. In terms of curiosity in conducting experimental activities, 91% of the students in the pre and post-test, declared they enjoyed accomplishing them.
We believe that all these experimental activities were very successful regarding all goals proposed, and its implementation in schools would result in great benefits for the students.

DISCUSSION

Experimental work has been used in schools for more than one hundred years, due to the influence of the experimental work developed in the universities. With these activities, it was intended to improve the learning of scientific contents, since students learned these contents but did not know how to put them into practice (Izquierdo *et al*., 1999). Gioppo and collaborators (1998) have demonstrated that experimental activities are important and relevant if associated with a proper methodology of discussion and analysis of the subject being studied.

Aware of this reality, teachers of *school E. B. 2, 3 D. Maria II* have carried out the activity called "Scientists for a Day", which had been previously developed by the ICVS/ECS University of Minho, Portugal (Azevedo *et al*., 2011).

We want to address the fact that after the participation in this activity, several improvements have been detected regarding the understanding and the application of concepts, data analysis and interpretation, as well as critical views.

Regarding specific contents, such as the importance of the nucleus of the cell, this activity was very successful. However, 23% of the students still said that the nucleus is important due to the fact that it is the centre of the cell; these results are similar to the ones obtained by Azevedo *et al*., 2011. On the subject of DNA existence and its visibility, the activity of extracting DNA was crucial. This activity stimulated discussion and led to a comparison of the results with other living beings and/or inorganic substances.

These results are similar to other studies that sustain the notion that an effective learning requires the creation of a learning environment in which students "manipulate" objects and "negotiate" meanings among themselves and teachers, in other words, experiencing a constructivist learning environment (Valadares, 2001). In what concerns the existence of DNA in water the student's revealed lack of knowledge, maybe the explanation could be some disorder between water and aqueous environment as was suggested by Azevedo *et al*., 2011.

When it comes to the contents developed in station "Acid/base", specifically the pH value of certain substances, despite having occurred significant improvements, some difficulties still persisted. This could be explained due to the fact that this activity wasn't properly explored because of the great number of substances that were to be tested.

Concerning questions about embryonary development not obligatory in the basic school, significant improvements have been confirmed. These aspects were developed through the observation of chicken embryos and the comprehension of the explicatory panels prepared by the teachers of the ICVS/ECS. We emphasize the fact that these experiments were the ones that the students felt more motivated. The students understood the similarities that exist between vertebrate embryos during the first stages of development and also understood the importance of studying chicken embryos as a model. By the same token, a recent study describes the importance of a scientific process which involves experimental work, data gathering and its analysis and interpretation, in a search for problem resolutions (Dibartolomeis and Moné, 2003). Nevertheless, recent studies have concluded that the teaching methods of Science Teachers are still based on theoretical teaching (Reis and Galvão, 2005). If this teaching method persists, the teachers will risk being the "chefs" of knowledge, preparing meals for an audience who does not have an appetite (Cury, 2004).

Concerning the interactions between sense organs significant improvements occurred between the pre- and post-test. Additionally, this study also demonstrated that it is easy to conduct experiences and all it requires are very simple materials.

Generally speaking, the results of this study were quite positive and, in certain aspects, they were even better than the ones obtained by Azevedo *et al.*, 2011. This may be explained by the following reasons: the experimental activities conducted in the school were structured considering the achievement of the predetermined objectives; the post-test was completed on the day of the activity; and finally, the fact that students were taught by other students, thus, making the process of learning more efficient, due to the fact that the language used was the same by all of them and when students have doubts, they do not feel inhibited to ask questions to their peers.

In competent learning, active student participation is essential, so that the individual is able to construct and reconstruct his own knowledge (Almeida, 1998). According to Revans (1982), active learning stimulates in the students a sense of greater responsibility, actively involving them and challenging them to think for themselves by promoting the exchange of ideas.

Notwithstanding certain limitations, for instance, the fact that we do not possess information regarding possible variables that may have influenced the results of this study, such as socio-economic conditions or intellectual levels, we consider this work relevant, since it translated in a fairly positive contribution to different aspects of student learning.

In conclusion, experimental activities should be explored to help students learn Science more efficiently, so that they can develop crucial and essential skills in the future. Nevertheless, given its potential, experimental activities should not be mere theories waiting to be conducted but should be put into action. Ultimately, it is the teachers' role to create constructivist environments and adopt investigative strategies.

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