

THE ROLE OF CRITICAL THINKING IN PHYSICS LEARNING

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ABSTRACT

Critical thinking is usually seen as crucial to Physics learning. This is clearly stated in the purposes of many Physics' curricula. In fact, since Dewey, several authors argue that critical thinking is fundamental to science learning. In order to clarify and to assess empirically the relation between critical thinking and pupils' performance in physics activities a research study is being undertaken. The study hypotheses (null hypotheses) are: 1) There is no significant statistical difference between the critical thinking level of the pupils that have a good performance in physics activities and the critical thinking level of the pupils that have a weak performance in physics activities; 2) There are no significant statistical differences in the way that different critical thinking aspects influence the pupils' performance in physics activities. The research follows an *ex post facto* design in a causal comparative model. A cross-national sample was constituted following a stratified group model, considering the schools and the Nomenclature of Territorial Units for Statistics II (NUTS II) and is constituted by 889 pupils of the 9th grade pertaining to 60 classes from 21 different schools. The Cornell Critical Thinking Test (level X) and a pool of physics activities specially designed and validated for the study were used as sources of data. The data are being analysed using the statistical software SPSS 15.0 with a multivariate model. It is expected that the results and conclusions of the study will awake the physics education community to the urgent need to move into practices deliberately designed to promote critical thinking and therefore, the conceptions of implemented curriculum will change. In order to promote physics learning, we also hope to be able to indicate to physics educators which critical thinking aspects are most important to demand explicitly our pupils to use.

KEYWORDS

Critical thinking, physics learning, assessment, physics curricula.

INTRODUCTION

Nowadays, there is an international agreement concerning the importance of developing critical thinking in science education as it is fundamental to science reasoning. In fact, authors like Hewitt (2002) claim, "science is a way of thinking as well as a body of knowledge". As a matter of fact, scientific reasoning involves a constant need of taking decisions and critical thinking is understood as "a process, the goal of which is to make reasonable decisions about what to believe and what to do" (Ennis, 1996). For example, using as a reference the Ennis Critical Thinking taxonomy (Ennis, 1987), we can say that science requires the use of elementary clarification abilities to identify or formulate a question; basic support abilities and elementary and advanced clarification abilities in order to search and select information in credible sources; inference abilities to design experiments, including planning to control variables and also the use of strategy and tactics abilities when presenting a written or oral report. Therefore, it seems that critical thinking has an important role in science learning and consequently, in physics learning. Surprisingly, almost one century ago, Dewey argued that science learning should develop the reflective thinking, which has become known as critical thinking (Dewey, 1933). More recently, in the report concerned with the promotion of scientific and technological literacy for all of the collaborative project of International Council of Associations for Science Education (ICASE), Southeast Asian Ministers of Education Organization Regional Centre for Education in Science and Mathematics (SEAMEO-RECSAM) and UNESCO Principal Regional Office for Asia and

the Pacific (PROAP) has clearly announced that higher order thinking skills, in which critical thinking is included, are a major component for science learning (2001).

The US National Science Education Standards outline “what students need to know, understand, and be able to do to be scientifically literate at different grade levels” (National Research Council, 1996) and also strengths the need to promote critical thinking. Several physics curricula of different countries show the same concern. The Physics Portuguese curricula for the middle and the secondary are no exception. For example, the purposes of the 10th grade Physics and Chemistry National Curriculum (Martins, Caldeira et al., 2001) state that “it is aimed that students should develop fundamental skills and attitudes (...) that enable them to be critical and participant citizens in society”.

Nevertheless, many teachers still do not pursue thinking skills. In fact, as several studies point out (Oliveira and Rodrigues, 2004; Rivard, 2004 and Newton, 1999), science classrooms are still strongly teacher directed, that is, the teaching and learning model used is mainly the transmission model that does not foster critical thinking. Others, since Dewey’s time till today have tried to promote pupils’ critical thinking but “their efforts were, and still are, largely unsuccessful” (Shamos, 1995). The ICASE; SEAMEO-RECSAM; and UNESCO PROAP (2001) report presents some reasons why teachers have not given much attention to higher order thinking skills or are unsuccessful in promoting them. The reasons are:

- a. Their belief that higher order thinking skills are part of a hierarchy of skills and cannot be acquired until lower order skills have been mastered;
- b. Their unwillingness to allow sufficient thinking time for students.

Therefore, it seems that the science education community urgently needs awareness of the importance that critical thinking has in science learning and needs to find ways to help teachers in accomplishing this target. The present study intends to be a contribution while trying to clarify and to assess empirically the relation between critical thinking and pupils’ performance in physics activities.

The study hypotheses, presented as null hypotheses, are: I) There is no significant statistical difference in pupils’ performance in physics activities between pupils with a high critical thinking level and pupils with a low critical thinking level; II) There are no significant statistical differences in the way that the different critical thinking aspects influence the pupils’ performance in physics activities.

METHODOLOGY

The research follows an ex post facto design in a criterion group or causal comparative model. This research design was chosen once we intended, without interfering, to analyse the facts as they really occur in classes. In fact, according to Cohen, Manion and Morrison (2000) “ex post facto research is a method of teasing out possible antecedents of events that have happened and cannot, therefore, be engineered or manipulated by the investigator”.

Population and Sample

The study population is the Portuguese 9th grade pupils, that is, pupils who are concluding the compulsory school.

The sample, a cross-national sample, was constituted following a stratified group model, considering the schools and the Nomenclature of Territorial Units for Statistics II or so-called NUTS II (European Parliament and Council of European Union, 2003). The option to consider NUTS II allows researchers to do comparative analysis with other European studies with the same kind of concerns. So being, the sample of the study is constituted by 889 pupils (409 male and 480 female) of the 9th grade with an average age of 14.64 years in 60 classes from 21 different schools and seven NUTS II, that is, from all Portuguese NUTS II.

Procedures

The Cornell Critical Thinking Test - level X (Ennis and Millman, 1985) was administered to collect data regarding pupils' critical thinking level and aspects. A pool of written physics activities specially validated for the study to assess pupils' performance in physics were also used. Pupils' personal data were collected.

Pupils' performance in the physics activities was assessed requiring them to demonstrate their achievement through a variety of primary traits: physics factual knowledge, the use of higher-order thinking skills, knowledge about the nature of science and attitudes toward science. Each trait was scored as present or absent or assigning points to certain aspects or qualities of the trait to arrive at a total assessment.

The data were collected in the last academic year personally by one of the researchers during classes with the presence of one of the pupils' teachers. The researchers' presence was important to get pupils' full collaboration.

The starting point to constitute the set of written activities was the science units of the comparative international study "Programme for International Student Assessment" (PISA). This particular study seemed to be a reliable source of activities since activities from PISA have been performed by a large number of pupils from different countries. They are concerned with different science contents areas including physics and they were deliberately designed based on the new trends for science education and by a large number of international experts.

A bank of 11 activities was initially compiled. They were selected from the PISA science units presented in OECD reports (2006, 2004, 2003, 2002, 2000 and 1999) and OCDE/PISA (2004). The activities were selected based on the following three criteria: 1) the content matter should be concerned with physics or they should apply to processes or knowledge used in science in general and therefore, also in physics; 2) they should be based on issues of major importance to the citizenship nowadays and 3) to be suitable to middle school physics curricula.

Keeping in mind the purposes of the activities, a validation study was conducted. A team of nine university experts constituted by three physics professors, two chemistry professors, two biology professors and two physics teachers educators all cooperated in the validation process. They performed the activities themselves and made comments. They gave their opinions regarding the contents and their accuracy, the items formulation, the clarity and the readability and the structure of the activities. Also, several middle school physics teachers gave their opinions concerning the appropriateness of the activities for the 9th grade physics and chemistry curriculum.

Besides, aiming to address the validity and the reliability of the set of activities, two sets of 9th grade pupils, not included in the sample but with the same characteristics, performed the activities. They were required to answer the activities and to complete a questionnaire intended to collect comments, critics and suggestions. The questionnaire also asked for input on clarity of the activities, comprehension of the questions, and if the concepts involved in the activities were recognized by them as concepts learned in the physics and chemistry discipline. It should be noticed that in Portugal, during middle school, physics and chemistry share a common course syllabus and are taught as a single science discipline by a single teacher.

The difficulty and discrimination indexes were calculated from the answers given by pupils to the activities. Wishing to select activities able to discriminate pupils' performance, only the activities with an average difficulty index and a high discrimination index were kept (TenBrink, 1974).

The final set of four activities with a total of twenty two items was the product that emerged from a dynamic process of re-conceptualization of the initial set of activities using the inputs of the team of experts, middle school teachers and pupils.

As one short example of one of the activities used in the study, let's consider some of the items of the activity based on "Flies" (OECD, 2000). After an introductory text, pupils must answer the following questions:

1. The farmer suspected that the insecticide could have changed with age. Briefly explain how this hypothesis could be tested.
2. The farmer suspected that the insecticide could have changed with age. Present two alternative explanatory hypotheses.

In the first question it is expected that pupils design a way of testing a hypothesis. The planner must identify and clarify the several steps that followed one by one, in a deductive way, tests the hypothesis. In the second question it is expected that pupils find plausible reasons for the situation presented in the text, using inductive reasoning, in order to come up with a general statement that can take the form of an alternative explanatory hypothesis.

This example clearly shows that the items of the activities require critical reasoning as part of science reasoning.

Data Analysis

The data have been analysed using the statistical software SPSS 15.0.

Hypothesis I: There is no significant statistical difference in pupils' performance in physics activities between pupils with a high critical thinking level and pupils with a low critical thinking level.

In order to test the first hypothesis of the study it was necessary to constitute groups regarding the pupils' critical thinking level. Three equal percentile groups were constituted. The middle group was not considered in order to have clearly defined groups of high critical thinking and low critical thinking levels. Then, an independent-samples t-test was conducted to compare the performance in physics activities between the two different groups of pupils. The effect size was calculated using eta squared.

A linear regression was also performed to analyse the relationship between the variables of pupils' critical thinking level and pupils' performance in physics in order to find an underlying correspondence between the variables involved.

Hypothesis II: There are no significant statistic differences in the way that the different critical thinking aspects influence the pupils' performance in physics activities.

In order to test the second hypothesis of the study a standard multiple regression was performed considering the pupils' performance in physics activities as the dependent variable and the several aspects of critical thinking as the independent variables. The aim was to find the best set of variables to predict the dependent variable. Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity.

Finally, another t-test was done to find out if there was a significant difference in the mean of the pupils' critical thinking levels for the groups' high performance in physics and low performance in physics. Naturally, before performing this t-test it was necessary to create the groups. Once more, the groups were designed considering equal percentiles to create three groups, eliminating the middle group for effects of analysis. The effect size was calculated using eta squared.

FINDINGS

Concerning the first hypothesis of the study, the results of the independent-samples t-test conducted to find out if there is a significant difference in the mean of the pupils' performance in physics for the groups' low critical thinking levels and high critical thinking levels, the results show that there is a significant difference in the mean of the pupils' performance in physics for the group of low level of

critical thinking ($M = 4.11$, $SD = 1.98$) and for the group of high critical thinking level ($M = 6.29$, $SD = 2.10$); $t(598) = -13.00$, $p < 0.0005$ (two-tailed). The magnitude of the differences in the means (mean difference = -2.17 , 95 % confidence interval: -2.50 to -1.85) is large (eta squared = 0.220).

The results of the linear regression performed between pupils' critical thinking levels as the independent variable and pupils' performance in physics as the dependent variable reveal that 18.7 % of the variance in pupils' performance in physics activities is explained by pupils' critical thinking level. In fact, R for regression was significantly different from zero, that is, $F(1, 887) = 204.55$, $p < 0.0005$, with R^2 at 0.187 . The adjusted R^2 value is 0.186 , which indicates that 18.6% of the variability in pupils' performance in physics is predicted by the critical thinking level. The unstandardized coefficient B is 0.093 ($SE = 0.006$) and the standardized coefficient β is 0.433 with $p < 0.0005$.

Regarding the second hypothesis of the study the results of the evaluation of assumptions show that the assumptions were not violated. The results of the standard multiple regression used to assess if critical thinking aspects (induction, deduction, observation, credibility and assumptions) are predictors of the pupils' performance in physics show that more than one fifth (21 %) of the variability in pupils' performance in physics is predicted by the critical thinking aspects. In fact, R for regression was significantly different from zero, $F(4, 884) = 58.69$, $p < 0.0005$, with R^2 at 0.210 . The adjusted R^2 value is 0.206 .

The results regarding each one of the critical thinking aspects: induction, deduction, observation and credibility and assumptions as independent variables are presented in Table 1.

Table 1. Summary of standard multiple regression analysis for variables predicting pupils' performance in physics activities

Variables	B	SE B	β
Induction	0.131	0.022	0.199
Deduction	0.231	0.027	0.351
Observation and Credibility	0.089	0.024	0.123
Assumptions	-0.162	0.049	-0.128

Note. $p < 0.0005$ for induction, deduction, observation and credibility. For assumptions $p = 0.001$.

The table displays the unstandardized regression coefficients (B), their standard errors ($SE B$) and the standardized regression coefficients (β). The size and direction of the relationships suggest that a higher performance in physics activities is obtained by those pupils with the critical thinking aspects induction, deduction, observation and credibility more developed. However, deduction seems to play the more important role as indicated by the unstandardized regression coefficients, followed by the induction aspect.

Concerning the other t-test performed in order to find out if there was a significant difference in the mean of the pupils' critical thinking levels for the groups' high performance in physics and low performance in physics, the results reveal that there is a significant difference in the mean of the level of critical thinking for the group of low performance in physics activities ($M = 14.13$, $SD = 9.43$) and for the group of high performance in physics activities ($M = 24.25$, $SD = 10.03$); $t(602) = -12.72$, $p < 0.0005$ (two-tailed). The magnitude of the differences in the means (mean difference = -10.12 , 95% confidence interval: -11.69 to -8.56) was large (eta squared = 0.212).

CONCLUSIONS

This paper, as it was its purpose, empirically demonstrates that good performance in physics requires critical thinking.

As a matter of fact, the results show that we can disprove the null hypothesis (I) of the study since there is a significant difference in the means of the pupils' performance in physics between the groups with lower and higher critical thinking levels. Moreover, the results of the linear regression performed point out that the critical thinking level is a predictor of the pupils' performance in physics. In fact, the results of the linear regression performed between pupils' critical thinking level as independent variable and pupils' performance in physics as dependent variable reveal that 18.6% of the variability in pupils' performance in physics is predicted by their critical thinking levels.

According to the results, we can also disprove the null hypothesis (II) as they show that the critical thinking aspects of deduction and induction are the most important aspects of critical thinking responsible for a good performance in physics. Consequently, the learning activities and teaching strategies should focus especially on these two critical thinking aspects.

The activities used to assess pupils' performance in the context of the present study follow this trend. In fact, as shown on the former example given (see Methodology), physics learning activities that require that pupils to interpret statements or texts, formulate hypothesis, design experiments, take decisions considering alternatives and consequences, draw and evaluate conclusions require deductive or inductive skills. Similar results regarding physics problem solving activities were found by Rodrigues and Oliveira (2001). Consequently, these kinds of activities should be more implemented in physics classes individually or in sets.

Not surprisingly, the results also show that there is a significant difference in the means of the pupils' performance in physics between the groups with lower and higher critical thinking levels. It can be stated that pupils' performance in physics is a predictor of the critical thinking level. This should not be odd. If we all agree that scientific reasoning clearly involves critical thinking it should be expected that pupils with a higher performance in physics also have a higher critical thinking level. Therefore, the relation between critical thinking and pupils' performance in physics seems to be bidirectional. In a nutshell, it seems that developing pupils' critical thinking contributes to improve performance in physics. Simultaneously, to perform physics activities demanding scientific reasoning contributes to develop pupils' critical thinking.

This close interrelation between critical thinking and performance in physics activities confirms the authors' idea that it does not make sense to enhance critical thinking and physics learning separately. They should be learned and taught intertwined through the use of strategies and activities specially designed to meet the two purposes.

It's time to change physics teaching. Teaching physics is still too frequently centred on a transmissive approach demanding the memorization of physics equations, principles and laws or the performance of mere exercises based on a drill approach. This way of learning physics is boring and uninteresting for young people and does not meet the actual requirements of society and of the new trends of physics curricula.

The results of the study reinforce that the curriculum put into practice by teachers must demand critical thinking infused into physics contents in an explicit and intentional way.

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