



Teaching experimental design to elementary school pupils in Greece

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Abstract

This research is a study about the possibility to promote experimental design skills to elementary school pupils. Experimental design and the experiment process are foundational elements in current approaches to Science Teaching, as they provide learners with profound understanding about knowledge construction and science inquiry. The research was carried out in pupils of an elementary school in Greece, who participated in the Science Club, which is composed of learners with interest and talent in the science subject. This club was formed in the year 2013-2014. Up until the year 2015-2016, totally 42 pupils have participated. All of them were involved in experimental design tasks. Through a qualitative research, it was examined whether the learners got familiar with the basic dimensions of experimental design. These are precision of variables, hypothesis stating and clarification of measurements and observations. Findings were overall positive. However, there is room for improvement.

Keywords: Experimental Design, Elementary School, Gifted and Talented Children.

Current Approach in Science Education

Science teaching, according to recent approaches should focus on a series of practices, which are: 1) Asking questions and defining problems, 2) planning and carrying out investigation, 3) constructing explanations and designing solutions, 4) analyzing and interpreting data, 5) developing and using models, 6) obtaining, evaluating, communicating information and 7) engaging in argument from evidence (NGSS, 2013).

These practices contribute and are contributed by the promotion of scientific thinking to learners. This approach prevents science teaching from being restricted to simple memorization of concepts, information and phenomena. Developing scientific thinking to learners is a complex process, depending upon certain conditions. Even though there are different views in literature about these conditions, there is general agreement of the need for constructing concepts, developing skills, familiarization with methodology process and adopting attitudes. Understanding of relationships between concepts or phenomena is significant.

Three different stages to the development of scientific thinking have been described. The first is strategic thinking. At that stage, learners understand relationships between concepts, such as the relation between the amount of a substance that the possibility of a solvent to dissolve it. The second stage is metastrategic thinking. This includes familiarization with the nature of science knowledge. Learners at that stage understand that knowledge is not static and can be re-negotiated and re-defined. They understand that science knowledge is dynamic; it is evolving and is a product of continuous, group work. Finally, the third stage of epistemology is the stage where learners are able to participate in science discourse, exchange observations, thoughts around science issues based on findings and data.

Teaching needs to serve transition across these stages in order to promote development of science thinking to learners (Kuhn et al, 2008).

The experiment in Science Teaching

The need for experimentation

Teaching science is largely based in developing skills, such as observing, measuring, hypothesizing, testing and experimenting. Experimentation as well as experimental design are among the basic goals of science subjects (NGSS, 2013).

An important goal of an experiment is to define the relationship between phenomena or concepts so as to answer a pre-stated scientific question. By including the experiment in a teaching intervention, learners have the opportunity to attend, understand and familiarize with scientific method of knowledge construction which they will adopt. This method depends on observing, hypothesizing, experimenting, justifying, testing and drawing conclusion, which is in accordance with the scientifically approved knowledge (Ryu & Sandoval, 2012).

Learners' familiarization with the experimental process and experimental design qualifies them with a more precise idea of the science subject, which will lead them to approach knowledge, research and development more critically.

However, this hides challenges for the educators. Teaching experimental design requires familiarizing and applying sets of rules, which should be followed by all learners in all experimental tasks. These rules are complex. This familiarization requires the appropriate knowledge, skills and attitudes concerning experimentation on behalf of the learners. Certainly this should not only be restricted in theoretical presentation from teacher to learners. Continuous practice on experiments is necessary for learners to understand and apply it better (Stafford et al, 2010).

The basic points of experimental design

Experimental design requires clarification of basic parameters concerning the need, the process, the context and the general development of the experiment.

Firstly, the variables of the experiment should be clarified. A variable can be any factor relevant to the experiment or scientific question and can change in terms of amount or quantity, such as mass, volume, time, humidity, temperature. For example, when designing an experiment to examine the importance of light in the growth of plants, variables interfering can be the light, along with any factor that can demonstrate growth, such as size, duration of size change, leaf color (Cutting & Kelly, 2014).

In every experiment there is the independent variable. This variable is a factor that can change autonomously or as desires the group that carries out the experiment. In the example of the experiment that examines the relationship between light and plant growth, the light is the independent variable.

The experiment is a process to precise the relationship between the independent variable with another one, the dependent variable. In the experiment of the plant, plant growth can be considered as the dependent variable. In order to get valid and accurate data from an experiment it is important to clarify the independent and the dependent variable. This approach is necessary but it requires thorough attention and investigation (Cutting & Kelly, 2014).

When carrying out an experiment it is necessary to give different values to the independent variable, in order to see how the value of the dependent develops. This will help defining the relationship between them. Sometimes it is necessary for those measurements to be carried out multiple times. It is therefore necessary to quantify these variables. This can be done normally with numerical values. In that case the variables need to be measured. If this is not easy, depending on the context of the experiment and the means available, it is also possible to be done by inventing categories or classifications, such as 'strong light', 'medium light', 'weak light'. In such a case, it is also suggested to precise a 'normal', or 'usual' value. (Cothorn et al, 2000).

The accuracy of the results that an experiment can provide depends on the repeated trials that can be carried out. In the experiment testing the relationship between light and plant growth, these repeated

trials can be done by letting similar plants to grow in places with different light intensity. The number of repeated trials depends on the context where the experiment is carried out.

There are certainly other factors that can influence the concept or phenomenon that the experiment tests. In what concerns plant growth, apart from light, factors mediating can be the type of the plant, room temperature, humidity. The value of these factors, so called 'controlled variables' or 'constants', needs to be similar for all plants examined.

A factor of course can be used in an experiment as an independent, dependent or controlled variable. This is arranged by the context or the scientific inquiry that the experiment tries to answer (Foulds & Rowe, 1996; Cutting & Kelly, 2014).

Apart from the variables, another important parameter in experimental design and carrying out is the statement of the hypothesis. Hypothesis which needs to be clarified and concrete can help the orientation of the experimental process. It assists learners in focusing their attention to the topic under study. By stating a hypothesis, learners can demonstrate whether or not they have understood what variables they examine and what the experiment aims at. Moreover, their ideas and misconception are elicited. These can serve as foundation to construct new knowledge. By benchmarking the hypothesis with the experiment results, learners go through the phase of the socio-cognitive conflict, which will help them adopt scientifically approved knowledge and reject false ideas they may have formed and carry (Driver et al, 1996).

Experimental design by pupils

Knowledge construction in science teaching is described through research to include three specific phases. The first is the formation of the research question. The second is the statement of the hypothesis. The third is the design and implementation of the experimental process. This last phase concerns data collection, data analysis and management. All knowledge, skills and attitudes developed within a teaching approach are orientated to these phases (Girault et al, 2012).

Science teaching therefore, according to recent approaches should not be limited to the implementation of preplanned actions to construct knowledge. These approaches underline the necessity for learners to participate in actions and tasks, such as planning experiments. Through such tasks, learners will become qualified with skills such as critical thinking that will help them get involved with problem solving relevant to scientific and innovative topics. This assists significantly the adoption of positive attitudes towards science subject (Ross & Robinson, 1987).

Charging learners with the duty to plan experiments is an opportunity for them to engage in creative tasks relevant to science methodology, inquiry and discourse. These are important dimensions of science work. This helps learners understand that the experiment aims to precise relationships and answer science question. In short, learners working on experimental design can not only construct knowledge more effectively but understand about the nature of scientific knowledge and work through a creative route (Ryu & Sandoval, 2012).

Chin and Malhotra (2002) define certain processes, which a learner has to follow in order to design experiments, similar to the process followed by scientists-researchers. Firstly, the question needs to be clarified. Then, all variables have to be identified. The hypothesis is then stated through clarification and precision of the process of the experiment. Finally, measurements are planned. This serves as a basis for experiment implementation through observation, data collection, generalizing and knowledge constructing. This set of processes is compatible with experimental design carried out by professional researchers (Cothorn et al, 2000; Cutting & Kelly, 2014). It can therefore be used as means to evaluate familiarization of learners with epistemological approach to knowledge (Chin & Malhotra, 2002; King et al, 2016).

Challenges in experimental design by pupils

Teaching experimental design to pupils is not easy to implement. The basic challenge arises because of the general culture and perception around learning and teaching generally and specifically in the science subjects. This culture focuses on learning specific knowledge. Any experimental task included in textbooks or curricula is oriented to this knowledge. Promoting science thinking, along with

experimental design is not a basic goal. In other words curricula emphasize mainly in knowledge and not so much in skills, attitudes and other elements that are basic to teaching and learning experimental design (Ross & Robinson, 1987).

This challenge can be overcome with the appropriate teaching interventions, which should focus on skills and qualities that learners need to improve in science thinking and experimental design. Within these interventions the basic characteristics of the experiment and science thinking are presented, through tasks that reinforce active participation of learners. Moreover, oral and written linguistic skills are developed. Such actions do not always bring in the expected results. They require time, infrastructure such as space and the appropriate means. It is not easy for teachers to involve them in a structured syllabus and context and teach it simultaneously (Ryu & Sandoval, 2012; King et al, 2016).

Ross and Robinson (1987) emphasized the need for writing and applying rules that will help learners catch up to, suggest ideas and thoughts about the process of an experimental procedure. The form of these rules depends on the learners' context and the general aim of the subject. In the case of experimental design, a simple rule is known as the '2 x 2' model. According to this model, the scientific question should be simplified so as to examine two variables with two values. By giving two values to the independent variable, it is possible to identify how the dependent variable performs and precise the relationship between these two. This rule can help clarification of the question and its link to the experimental process. Another rule can include the basic stages of experimentalism written down and presented, so as to be followed. These stages can relate to identifying means, what to measure, saying a hypothesis, writing down measurement. Writing and applying rules is certainly not easy.

So teaching experimental design, as part of science thinking generally, should focus on its basic characteristics and rules setting. This approach is justified to assist, in condition of course of the assistive context (Ross & Robinson, 1987; Ryu & Sandoval, 2012; King et al, 2016).

The research context

The Science Club

This study aims to research the effective implementation of teaching experimental design to primary school pupils. The research was carried out in a primary school in Greece. The learners of the study were members of the Science Club of the School. The Clubs are an institution that addresses to learners with interest and talent in specific subjects, such as science. They were implemented in the so called experimental schools in Greece by law in 2011. The experimental schools are public schools that differ from the mainstream as they are expected to emphasize more on research and innovation, serving as context for implementation and evaluation of new teaching practices and institutions (Law 3966/2011).

The planning and function of the Science Club was founded on two pillars. The first is the principles of science education. The second one is the principles of gifted and talented learners' education.

Defining gifted and talented learners is food for debate in literature. Rinn (2012) supports that gifted learners generally demonstrate attributes such as motivation, intention to experiment and research, enthusiasm for cooperative work to solve problems and deepen knowledge and engagement in the area they are talented.

Therefore, any intervention addressing to such learners, should promote knowledge, skills and attitudes that will help them deal with problem solving and aspire them to specialize further in the subject they are interested, such as Science. Moreover, it should fill them with the ambition to contribute to this field. This intervention should not be restricted to knowledge and skills solely. It should promote self-confidence and belief that they can enrich this subject (Subotnik et al, 2011; Rinn, 2012; Ziegler et al, 2012; Wegner et al, 2016).

The context of the science club was selected as appropriate for this research for two reasons. The first was the compatibility of experimental design tasks to the principles of gifted and talented education. That's because experimental design is based on developing skills and attitudes about scientific

phenomena and research (Girault et al, 2012; Ryu & Sandoval, 2012). The second was the flexibility offered to the educator responsible of the Club, to select the approach, the aims, the topics to be taught and the actions to be carried out. There is no curriculum or syllabus prescribed for the clubs. Any teacher willing to arrange one has to design a syllabus, submit it to the Board of Experimental Schools in Athens. As soon as it is approved, the club is composed and starts working (Law 3966/2011).

In the school of the study, the Science Club has been running during the years 2013-2014, 2014-2015 and 2015-2016. Totally 42 learners have participated in this club. All of them were learners of the final grades of elementary school, the 5th and 6th, aged 10 to 12.

As both the law and the research suggests, participation in the Club is voluntary. Any pupils wishing to participate in a Club need to apply, along with their parents. There is a first evaluation of the pupils, which assist in observing progress, in what concerns actions, knowledge and skills on the topics that each Club negotiates (Law 3966/2011; Rinn, 2012; Wegner et al, 2016).

Experimental design tasks

The pupils of the Club were engaged in experimental design tasks. The topics of these tasks were relevant to the units of the science subject as set by the National Curriculum of Greece (DEPPS, 2003). During that initial stage of the pupils with experimental design, the question of the inquiry that the experiment would focus on would be presented in an orientation stage of the teaching intervention. An example of such a task, from the unit of mixtures and dissolutions was '*We have learnt that the quantity of substance that can be dissolved in a solvent depends on the nature of the substance, the quantity and temperature of the solvent. Does it on the nature of the solvent?*'. In some other cases, children were asked to reconstruct experiments that were studied. One example was: '*What can design experiment to prove that heat is transmitted to the solid objects by conduction?*'

Before getting started, there was discourse and teaching around the nature of experimentalism, the importance of the experiment in science, the process and steps that should be followed. Attention was paid so that learners would understand that the experiment aims to identify relationships between concepts. This way, they would find it easier to precise independent, dependent and controlled variables. Attention was also paid in stating hypothesis. Moreover it was explained that measurements to be done should be identified. These qualities would help learners get a basic plan of the experiment they are designing. That would help them select the appropriate means and complete the description of the experimental process (Ross & Robinson, 1987; Cothorn et al, 2000; Chin & Malhotra, 2002; Ryu & Sandoval, 2012; Cutting & Kelly, 2014; King et al, 2016; Wegner et al, 2016).

Within the Club, 32 total tasks of experimental design. Ten to twelve tasks of experimental design, were carried each year. This was the maximum number possible, bearing in mind that the club was for only two hours per week. Pupils would be members of the the Club for one or two years.

At the begining of each tasks, learners were given spreadsheet, where they would take down notes about the experiment, they would design, such as the materials they would use, the hypothesis, the concepts they would measure or focus on.

Research Questions

Experimental design by learners is very important in science subjects. It is a complex process to implement. In an experiment, it is important initially to precise the scientific question that has to be answered. It is important to clarify independent, dependent and controlled variable. Hypothesis needs to be formed as this will be an axis for the design of the experiment. It is also important to clarify measurements and observations that will be done. Pupils who design experiments should understand these points. Writing out sets of rules can help (Ross & Robinson, 1987; Cothorn et al, 2000; Chin & Malhotra, 2002; Ryu & Sandoval, 2012; Cutting & Kelly, 2014).

The answer to the general question of the study, if the pupils become qualified to design experiments, will be negotiated by researching whether the pupils respond to the demands that effective experimental design requires. In other words the research questions should focus on finding if learners became familiar with the basic points of experimental design (Foulds & Rowe, 1996). Therefore, the research questions are formed as follows: 1) Did the learners clarify the variables of the

experiment?, 2) Did the learners state a hypothesis?, 3) Did the learners precise the measurements they will carry out?

Research Methodology

This research is more of qualitative nature, as it focuses on studying attitudes of people within a specific context, instead of statistically justifying a hypothesis. Data to be analyzed in a qualitative research may come from interviews, questionnaires, notes, biographies or observations. The selection of the appropriate data collection techniques depends on the nature and the questions of the research (Cohen et al, 2011). For the purpose of the specific study, data derived from three techniques. Notes on learners' projects about experimental design, such as spreadsheets, were analyzed. Moreover, pupils took part in group semi-structured interviews. Lastly, there was observation of the teaching interventions.

Overall, 32 observations were carried out. The interviews took place, at the end of each task.

Specifically, for the semi-structured interviews there was a guide. To answer the first research question, the guide included questions focusing on understanding and clarifying the variables of the experiment to be designed, such as *'what exactly do you examine here?'*, *'what concepts do we study?'*, *'is there a relationship between them?'*, *'Does one affect another? How?'*, *'What should we change? What should we keep the same?'*.

To answer the second research question, the interview guide would include questions concerning hypothesis statement. Such questions were *'what do you expect to see?'*, *'why do you think this will happen?'*, *'what do you think must change, if we want to have another result?'*.

Finally, to answer the third research question, the guide included questions concerning measurements, observations and how they would be done, such as *'how can we find what is the relationship between the concepts we examine?'*, *'will we note down anything?'* (Foulds & Rowe, 1996).

By combining answers to the interviews with notes and observations, data were triangulated, so that the findings would be more accurate. The interviews and observations were transcribed. Analysis of them was based on the and analysed (Cohen et al, 2011).

Results

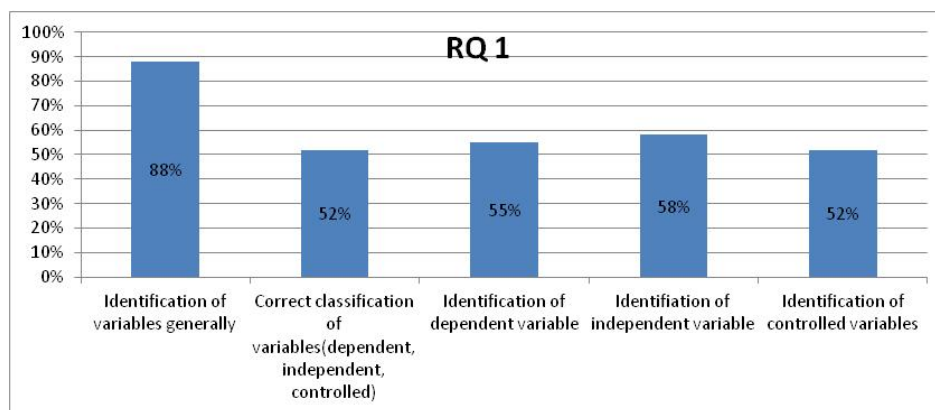


Figure 1. Research question 1: Identification of variables

1st research question

Findings of the first research question were overall positive. Learners managed to clarify variables that the experiment under study would test. There were few challenges in identifying the independent and dependent variable. There were cases where pupils needed time to understand and express which concept affects which. They also expressed difficulty in identifying controlled variables. It was difficult for them to understand or explain why they should not change. Moreover, there were learners influenced by previous experiments they had come across, they attributed a characteristic role to a concept, which they considered unchanged. For example, as they had come

across experiments, where temperature was a controlled variable, they had difficulty to understand that in other experiments, in other contexts temperature could be an independent or dependent variable. This was more frequent in the initial tasks of experimental design. These impediments were overcome with the help of discussion and setting rules about experimentation.

These findings agree with research. Clarifying variables is an important challenge (Cutting & Kelly, 2014). By clarifying and simplifying variables, using models such as the '2 x 2' of Ross and Robinson (1987), and by promoting rules and linguistic skills about experiments, (Foulds & Rowe, 1996; Cutting & Kelly, 2014) learners become more able to design experiments, which will help them become more familiar with the epistemological level of science thinking (Chin & Malhotra, 2002).

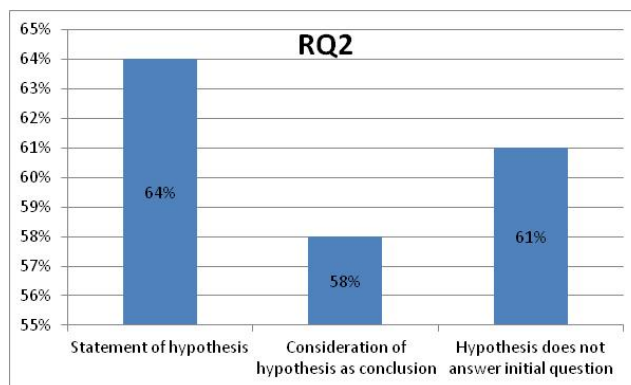


Figure 2. Research question 2: Stating hypothesis

2nd research question

The findings concerning the second research question were rather not positive, especially in the beginning of the project. Initially, as seen from the first observations and spreadsheets, most pupils paid little attention to stating a hypothesis. As they showed in their explanations in interviews, they did not consider it rather important. Various pupils stressed that they 'need to do the experiment first to see what will happen', giving the impression that they confused the hypothesis with the observations and the conclusion that the experiment would lead to. Such replies and responses reveal limited understanding of the importance of hypothesis in experimental design. They specifically reveal certain barriers on behalf of the pupils to get involved in expressing ideas and thoughts about the experiments (Ryu & Sandoval, 2012; King et al, 2016) and generally about science thinking (Kuhn et al, 2008).

After being involved in four or five experimental design tasks though, with the revision and re-application of rules, most pupils understood the need to state a hypothesis. There were many cases though, where the hypotheses did not answer the initial scientific question. This is probably due to lack of understanding this question that the experiment would answer. It can also be attributed to superficial understanding of the rules from the side of the learners (Foulds & Rowe, 1996).

So hypothesis statement was not carried out appropriately by the learners. As concluded by other research, setting rules helps, but it is not sufficient to assist learners understand the need to hypothesize (Ryu & Sandoval, 2012).

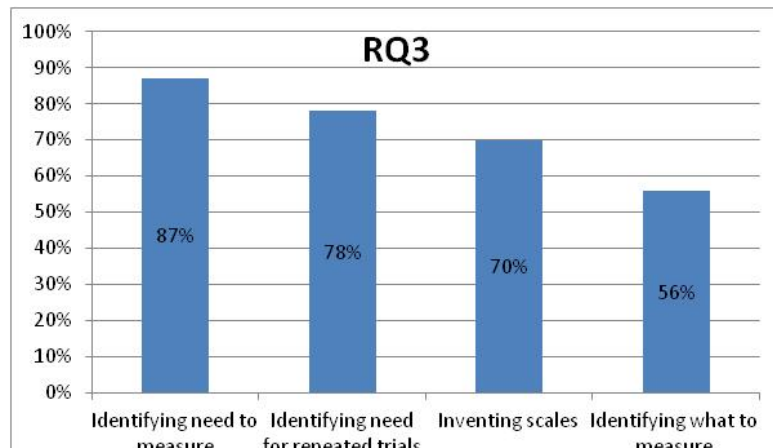


Figure 3. Research question 3: Clarifying measurements

3rd research question

The findings concerning the third research question were overall encouraging. Pupils showed in the spreadsheets, observations and interviews that they considered measurements and observations as part of the experimental process. Indeed when discussing about an experiment they kept mentioning they need to measure. In the beginning, they faced challenges in inventing scales as such task was unknown to them. After seen examples of such invented scales, such as 'strong light', 'weak light', 'close to the sound source', 'far from the sound sources', they got familiar with this approach. This shows familiarization with measurements as part of the experimentation, in combination with the means available (Cothorn et al, 2000).

Pupils also showed understanding of the need for repeated trials in experiments. They showed provision to give different values to the independent variable, in order to see the progress of the dependent. However, a challenge that was observed was to precise the variables to measure and study. There were pupils that could not focus on the particular variables the experiment should address to and design measurement for all variables involved, even the controlled. This weakness might be linked to the lack of understanding of the role of variables as observed in the first research question. It might also be linked to the lack of understanding of the need for hypothesis, as observed in the second research question (Foulds & Rowe, 1996; Chin & Malhotra, 2002).

Conclusions

This study examined the possibility to develop experimental design skills in elementary school pupils. The experiment is an important element of science subjects. Involvement in experimental design assists in familiarization of learners with science discourse and development of science thinking (Chin & Malhotra, 2002; Ryu & Sandoval, 2012; NGSS, 2013; Cutting & Kelly, 2014).

The experiment aims to investigate relationships between concepts. The experiment has three basic dimensions. The first is the clarification of variables, which are the concepts that the experimentalist will work on to find their relationship. The second is the hypothesis. The third is measurements and observations. Pupils who design experiments need to focus on these dimensions. Teaching experimental design is not straightforward. The school context and working conditions of the teacher bring on barriers. Several practices, focusing on familiarization with experimentation, such as rule setting, have been suggested as helping (Ross & Robinson, 1987; Foulds & Rowe, 1996; Cothorn et al, 2000; King et al, 2016).

Having in mind the above, a study was planned to promote experimental design to pupils, in an elementary school in Greece. These pupils were members of the Science Club, as they have expressed interest and talent in the science subject (Law 3966/2011). Such pupils are frequently keen on deepening their knowledge in the field of their interest by inquiring planning, carrying out investigations and constructing new knowledge. Experimental design tasks were therefore appropriate for them (Subotnik et al, 2011; Rinn, 2012; Ziegler et al, 2012; Wegner et al, 2016).

The research was qualitative. Data were collected with interviews, observations and learners spreadsheet (Cohen et al, 2011).

Findings have shown that pupils managed to clarify variables and measurements when designing experiments. There was room for improvement in pointing out the exact relationship between variables and the exact measurements the experiments concerned. Moreover, there was difficulty in stating hypothesis.

Practices, as suggested by research assist to an extent (Ross & Robinson, 1987; Foulds & Rowe, 1996; King et al, 2016). Pupils understand that there are relationships between concepts and that knowledge in science is not static and can be re-negotiated. This shows achievement in conquering strategic and metastrategic level of science thinking. Pupils' participation in discourse shows part conquering of the epistemological level, which could have been complete if there was more focus on what concept is studied and how, within this discourse (Kuhn et al, 2008).

The overall findings of the study were therefore positive. This study though, researched a specific sample for a specific period of time. Additionally, at that initial stage, many of the experiments designed were not carried out, mostly due to time pressure. Any effort to generalize the findings of the study should take into consideration these limitations (Cohen et al, 2011).

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