The Science Fair as a Means for Developing Children's Graphing Skills in Elementary School

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Abstract. *This article reports on an ongoing research program aiming at the pedagogical exploitation of the science fair as a mechanism for developing investigative skills in elementary school and promoting student inquiry through a sequence of formal and non-formal activities. Specifically, this paper refers to the development of data graphing skills by children aged 10-12 years old. The students, who participated in the teaching intervention, were engaged in a process of undertaking and reporting on authentic investigations in order to contribute to a school science fair. The curriculum used in the present study, was drawn from the program "The Science Fair as a means of developing investigative skills". Qualitative and quantitative data were obtained from students' responses to paper and pencil open-ended tests, their notebooks and their posters, which were used as sources of evidence in the present study. Analysis of the results demonstrate children's ability levels on data graphing, difficulties that hamper students' attempts to develop and interpret graphical representations of data, differences between students' graphing achievements between pre-test, mid-test and post-test, and correlations between constructing graphs and interpreting information from graphical representations. This work clearly demonstrates that the construction of graphs needs to be taught systematically in elementary school in combination with other science investigation skills such as interpreting data.*

Keywords. *data graphing, formal and non-formal activities, investigative skills, interpreting information from graphs, science fair.*

1. Introduction

The rising interest expressed by researchers in reforming science teaching proposes to the promotion of a fundamental objective: to prepare students to participate in a scientifically literate and technologically dependent society as informed and insightful citizens. Curriculum designed for this purpose must provide special emphasis on the development of scientific thinking skills in the context of learning science [18].

The ability to construct graphs is important to science and it can be considered as oe aspect of an individual's scientific literacy [27, 31, 24, 1]. When arguing in favour of a specific theory, a scientifically literate person needs to manipulate data and refer to relationships as they emerged from evidence represented on graphs or tables. Graphs can summarize very complex information or relationships very effectively. The extensive use of computers, nowadays, has made easier the use of graphs as a way of representing data [29, 1, 26]. This has led to an increas in the visibility of graphical representations in the popular press and other mass communication media.

During the last years, the effective use of graphical representations in mathematics and science education has received special attention [25]. Still, there is considerable evidence to suggest that students perform poorly in tasks related to graphing procedures [24, 1]. We take the perspective that graphing strategies need to be systematically promoted in the context of learning science in elementary school within students´ involvement in broader inquiry - oriented activities that are close to their experiences and interests [10]. Hence, there is a necessity for designing teaching interventions aiming at the development of data graphing skills in elementary school through a combination of different learning styles.

The curriculum designed for the purposes of the present research study combines formal, non-formal and informal educational activities. Students who participated in the research, were involved in data graphing processes as part of the investigations they implemented for participating in a science fair. In this paper, we discuss the results regarding 10-12 year old children´s performance on data graphing, the difficulties that hamper their attempts to graph data and the necessity for a systematic promotion of this skill through science education.

2. Backround

2.1. Data Graphing

Investigation is a process central to science that involves both reasoning and procedural aspects [7, 5]. The ability to organize and implement an investigation can be analysed into specific investigative skills: the identification of variables, the formulation of questions, the experimental design and control of variables, data graphing, the interpretation of data from tables, graphs and combinations of independent sources and the identification of faults in experimental design are examples of such skills [16].

Graphing skills fall into the procedural part of the investigative procedure. Data the emerge from the investigation are organised represented concisely during this stage, which therefore assumes a productive role in sense making. In this context, the production of a graph is a part of a process of problem solving and not an end in itself [1].

Graphs are a flexible medium for displaying data, revealing relationships between variables and communicating the results [27, 31, 29, 24, 1, 26]. Graphs are often preferable to tables for the purpose of displaying data. Firstly, a graph allows the reader to quickly identify trends and relationships between variables and evaluate the strength of the relationships. Moreover, a graph distills a lot of information into a restricted amount of space [27, 31, 24].

The kind of graph chosen for displaying data depends on the type of the variables involved. A histogram is appropriate when the variables involved are categorical and a line graph is preferred when the variables are continuous. Constructing either histograms or line graphs requires some level of abstract reasoning ability. Construction of graphs "involves going from raw data (or abstract function) through the process of selection and labeling of axes, selection of scales, identification of units and plotting" [21]. The complexity in data graphing is identified by researchers [27] who analyzed the skill into other sub skills:

(a) drawing and scaling axes,
(b) assigning manipulated and responding variables to the correct axes,
(c) plotting points, and
(d) using a line of best fit in the case of a line graph or sketching the bars in the case of a histogram.

These subskills can be approached individually in science education as part of the development of data graphing skills [31, 9]. However, we take the approach that graphing skills are better developed in combination with other investigative skills in the context of authentic problem solving situations [19].

2.2. Interpreting information from graphs

The graphing process involves both construction and interpretation [24, 1]. Hence, graphing is sometimes defined as a unique skill that includes two aspects: construction and interpretation of graphical representations.

However, interpretation of information from graphs refers to the ability to read a graph and develop meaning from it. It relies on and requires reaction to a given set of data. This makes it different from the ability to construct graphs, which requires generating new parts that are not given [21].

As a result, the two skills (construction and interpretation of graphs) are approached separately in our educational design. The interpretation of graphs was also analyzed into subskills [27]:

(a) determining the X and Y coordinates of a point
(b) interpolating and extrapolating
(c) stating relationships between variables
(d) interrelating the results of two or more graphs.

Accurate interpretation of evidence relies on good data handling [9]. Hence, the ability to construct graphs would be expected to relate to the ability to interpret information from graphs. The two skills would be expected to interact throughout their development.

2.3. Difficulties related to Data Graphing

Several studies, that examined graphing tasks, showed that students encounter various difficulties in their attempt to make their own graphical representations [27, 31, 24]. Approaching graphs as pictures is mentioned by researchers as one of the difficulties students come across [21]. Another difficulty refers to student's ability in drawing the best fit line [27]. The construction of a series of graphs, each representing one aspect of the data, was also identified as a difficulty [24]. Difficulties that are common in both interpreting and constructing graphs strengthen the hypothesis that there is a strong relationship between the two skills through their development.

These difficulties seem to function as obstacles to students' efforts to construct graphs and they often make them feel a general lack of competence in graphing. As a result, they prefer constructing a table than a graph and they often draw conclusions with little or no reference to their graphs [27, 9]. The research literature also declares that many teachers seem to recognize that pupils have difficulties in constructing a graph, but only few teach graphing strategies explicitly [9].

2.4. Teaching Approaches

There is comparatively little mentioned in the literature about approaches aiming to systematically promote data graphing in science education. Graphing is often considered as a domain only of Mathematics. However, research has shown that many students cannot apply what they have learned about graphs in mathematics to science or other disciplines [23]. Hence, since data graphing is a part of the investigative procedure, it can and should be systematically addressed within science education.

Several research attempts demonstrate that students can improve their graphical techniques through computer-based learning environments, especially the process of interpreting and manipulating graphs [29, 1, 26]. Yet, students firstly have to be encouraged to construct graphs within paper and pencil activities, which is probably more meaningful and understandable for them and then become involved in activities with spreadsheets.

2.5. The Science Fair

The Science Fair is a non-formal learning activity in which students implement science projects and exhibit them to the public [30]. Educators internationally use the science fair activity for two main reasons. First, students participating in a science fair are encouraged to become involved in issues related to science and hence, they develop positive attitudes towards science learning. Second, parents have the opportunity to become involved in the learning process [3, 4, 8, 6, 12, 15].

There are relatively few examples of fairs that have clearly specified educational goals and are assessed for their learning outcomes. The very loose connection with the official curriculum is one of the disadvantages of science fairs that are usually acknowledged as the reason for considering them as celebratory school events without much emphasis on the learning outcomes [2, 13, 4].

However, our literature review suggests that when a science fair is used as a learning activity, the students participating:

(a) develop critical thinking skills, problem solving skills and social skills [3, 8]
(b) enhance their opportunities to develop an understanding of the nature of the work of scientists [4, 6, 13, 22].

In our research, the science fair is used as an extended instructional activity that combines formal, non-formal and informal activities and aims at the improvement of investigative skills in elementary school. According to the approach that has been developed, the science fair is the final stage in a long process, where students undertake authentic investigations related to simple questions of their own interest. They work collaboratively to implement an investigation in which they design experiments, collect data, construct graphs and formulate answers. The whole process culminates in a specially organized school event (*the science fair*), during which children display the procedures and results of their investigations and also engage in interactive activities that they have designed in collaboration with their parents in order to teach certain aspects of their investigation to visitors.

We used this teaching context to investigate the development of children's ability to represent evidence in graphical form. Two examples from the students' efforts to graph data for the purposes of their investigations are presented in figure 1.

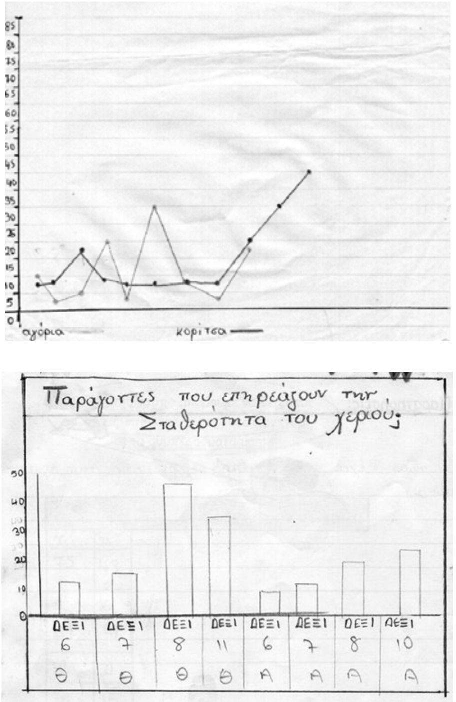

Figure 1. Examples of student's efforts on data graphing

3. Research study

3.1. Participants

Thirty-five 5-graders of a rural primary school in Cyprus participated in this study. The students were engaged in both the formal teaching intervention and the science fair.

The curriculum used in the present study, was designed for the purposes of the research program: *The Science Fair as a means of developing investigative skills, that is* implemented by The Learning in Science Group at the University of Cyprus. The program focuses on the pedagogic exploitation of the science fair as a means for developing investigative skills in elementary school and promoting student inquiry through a sequence of formal and non-formal activities. The teaching and learning materials, involve a handbook for teachers, a student workbook and an investigations' booklet [5]. Part of the material is available online for use by teachers, students and parents [17].

3.2. The Intervention Program

The study was divided into three phases, as shown in figure 2. In the first phase, the students participated in a teaching intervention, which took place in a formal classroom setting. One of the lessons was devoted to data graphing strategies. During the non-formal phase, students implemented their investigation collaboratively and interacted with other students, their teachers and their parents in preparation for their participation in the science fair. The children formulated investigative questions, designed and implemented valid experiments, described their procedure in a notebook and created a poster for displaying their methods and results. Whenever it was possible, the students constructed graphs to display their data. The actual science fair took place in the third phase of the research.

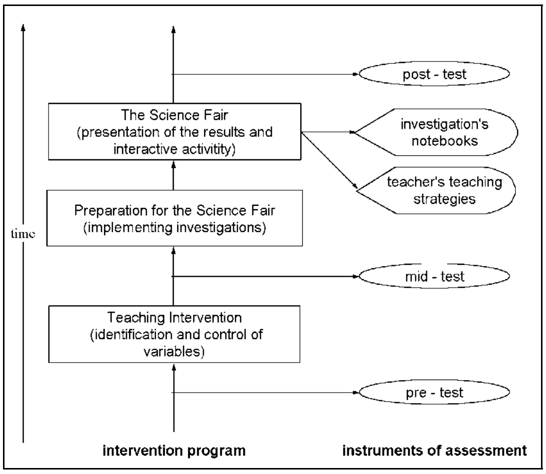

Figure 2. Organization of the research study

3.3. Method

For the purposes of the research study, paper and pencil open-ended tasks were administered to the research participants, before and immediately after the formal teaching intervention and after the Science Fair. Totally, four of the tasks aimed at evaluating students' abilities to graph data. Each instrument was administered at least twice during the study. Tasks 1 and 2 were included in the pre and post test. Tasks 3 and 4 were included in the mid and post test.

All assessment tasks presented unfamiliar situations that have not been encountered during the intervention. The context of tasks 1, 2 and 4 was associated with science experiments and the context of task 3 related to everyday situations that were not associated with science by the children. Moreover, in tasks 1 and 4 students were expected to construct histograms and in tasks 2 and 3 students were expected to construct line graphs. These were stringent criteria that helped us measure real learning as demonstrated by the ability for knowledge transfer.

Task 1.
Melina filled up 3 pots with water of different temperatures: pot A with hot water, pot B with lukewarm water and pot C with cold water. He measured the time needed to dissolve sugar in each pot and organized the data in the table below:

cup	time for sugar to dissolve
A-hot water	12 sec
B-lukewarm water	17 sec
C-cold water	30 sec

Construct a graph with the data displayed on the table.

Task 2.
Simon took two similar plants. He placed plant A in the light and plant B in the shadow. He measured the height of the plants every three days. He organized the data collected in a table as shown below:

day	1st	3rd	6th	9th	12th	15th	18th
height of plant A	5cm	6cm	8cm	10cm	12cm	13m	15cm
height of plant B	5cm	5cm	6cm	8cm	9cm	11cm	11cm

Construct a graph with the data displayed on the table.

Task 3.
Mr Manolis wrote in a table how many costumes and jackets were sold in his shop between April and August.

month	costumes	jackets
April	250	150
May	200	200
June	150	400
July	100	500
August	140	450

Construct a graph in order to compare the number of costumes and jackets sold in each month.

Task 4.
Leonidas investigated if the colour affects the extent of transparency of a surface. He used surfaces of four different colours: yellow, red, colourless and blue. He counted the number of surfaces needed to cover completely a specific drawing.

colour of the surface	number of surfaces
yellow	24
red	15
non-colour	29
blue	18

Construct a graph to display these results

Posters constructed by the students for the purposes of the Science Fair and their notebooks were used as additional evidence in the research.

4. Findings

Qualitative and quantitative data were obtained from the phenomenographic analysis of student's responses to the four tasks.
The results demonstrate:

- Ability levels on data graphing
- Difficulties that hamper students' attempts to graph data
- Significant student differences on graphing achievement on pre-test, mid-test and post-test
- A significant interaction between the skill of constructing graphs and the skill of interpreting information from graphs

Student's notebooks and posters were mostly used to identify difficulties that students come across in their attempt to construct graphs.

4.1. Description of Students' Responses

In tasks 1 and 4, most of the students constructed histograms as they were expected to. Before the intervention (as demonstrated by their responses to task 1), students had chosen the appropriate type of graph. However, most of them either scaled wrongly the axes or did not assign any variables to them. After the teaching intervention (as shown from their responses to task 4), a high percentage of students constructed the suitable type of graph (histogram), they assigned the corresponding variables and they scaled the axes correctly. At the end of the intervention program, in both tasks, almost everybody managed to assign correctly the corresponding variables and to scale the axes correctly in the histograms they created.

In tasks 2 and 3, students were expected to construct line graphs. Before the teaching intervention (as shown from their responses to task 2), most of the students assigned the variables in an inappropriate type of graph (a histogram) and they scaled wrongly the axes or did not scale them at all. The majority of the students did not assign the corresponding variables. Many of them did not offer an answer at all. In task 3, which was administered for the first time after the formal teaching intervention, many students again did not come up with an appropriate type of graph. Most of them constructed a histogram, without any or wrong scaling and assigning of the variables. In a high percentage of these responses, the axes were scaled correctly, but the variables were not assigned properly. After the science fair, the majority of the students still did not choose the appropriate type of graph to present the data in both tasks and they encountered several difficulties in scaling the axes or assigning the variables. Only a few of them constructed a line graph and assigned the variables and/or scaled the axes correctly.

The responses of the students on each task were analyzed phenomenographically. The groups that emerged were compared and organized in eight general categories, which were ordered hierarchically from the lower level to the higher. Finally, the responses in each task were classified into the levels described below.

4.2. Ability Levels on Data Graphing

The eight ability levels on data graphing, which derived from the phenomenographic analysis of student's responses, are:

Level I: S/he does not answer, or s/he does not understand the question or s/he simply reconstructs the given table

Level II: S/he does not choose an appropriate type of graph, does not assigns the corresponding variables and does not scale the axes

Level III: S/he chooses an appropriate type of graph, without assigning the corresponding variables or scaling the axes

Level IV: S/he does not choose an appropriate type of graph, but s/he

- assigns only the independent or the dependent variable, without or with wrong scaling of the axes
- assigns the independent variable with verbal reference to the dependent variable, without or with wrong scaling of the axes

Level V: S/he does not choose an appropriate type of graph, but s/he

- scales the axes correctly without assigning the corresponding variables, or
- assigns only the independent variable with correct scaling, or
- does not assign the independent variable, but s/he refers to the dependent variable verbally and scales the axes correctly, or
- assigns the independent variable with quantitative reference to the dependent variable, and correct but sometimes double scaling of the axes

Level VI: S/he chooses an appropriate type of graph, but s/he

- assigns the independent variable with quantitative reference, includes only verbal or no reference to the dependent variable and s/he scales the axes wrongly
- does not name the variables, but s/he scales the axes correctly
- assigns only the independent variable and does correct but double scaling of the axes

Level VII: S/he does not choose an appropriate type of graph, but s/he assigns the corresponding variables and s/he scales the axes correctly

Level VIII: S/he chooses an appropriate type of graph. S/he assigns the corresponding variables and s/he scales the axes correctly

Typical examples from students' responses are presented below:

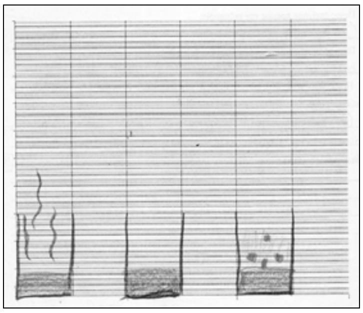

Figure 3. Example from task 1 – level 1

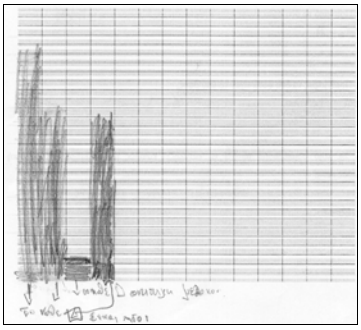

Figure 4. Example from task 4 – level 2

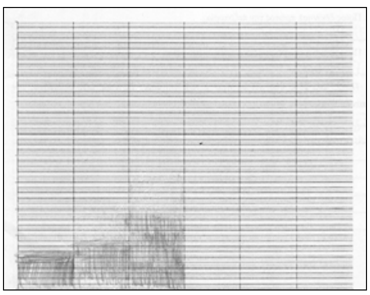

Figure 5. Example from task 1 – level 3

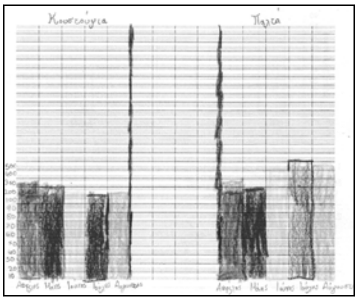

Figure 6. Example from task 3 – level 4

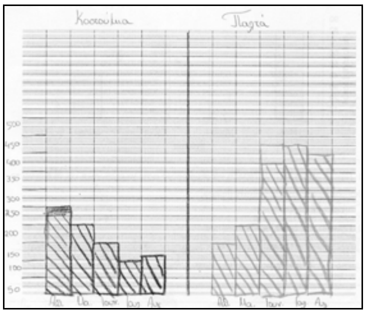

Figure 7. Example from task 3 – level 5

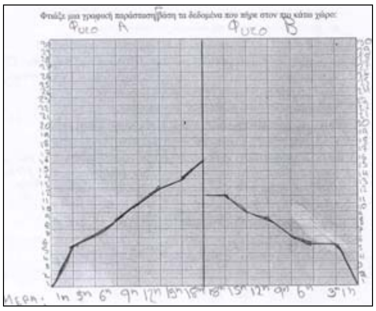

Figure 8. Example from task 2 – level 6

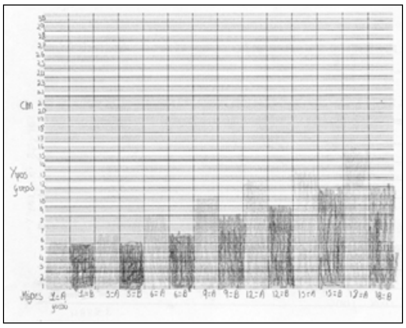

Figure 9. Example from task 2 – level 7

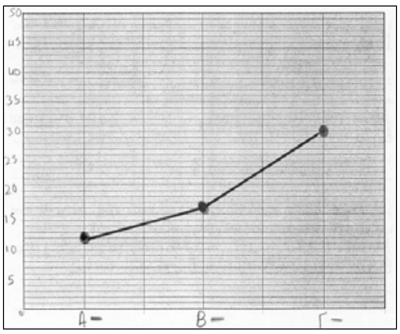

Figure 10. Example from task 1 – level 7

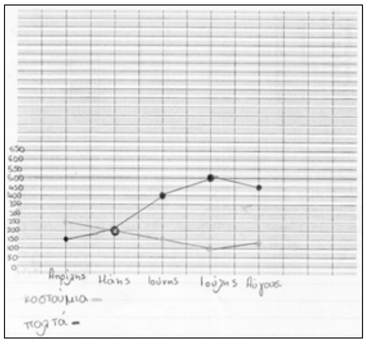

Figure 11. Example from task 3 – level 8

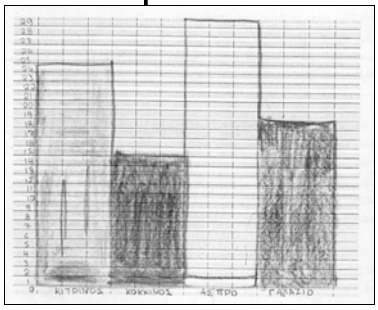

Figure 12. Example from task 4 – level 8

4.2. Student Difficulties with Data Graphing

The students seemed to encounter various difficulties with graphing. Three of them are given below with typical examples:

<u>Difficulty 1:</u> Students tend to construct histograms rather than line graphs, even when the dependent variable is continuous. They understand that they have to display the variation in the values of the corresponding variables, but they prefer a histogram in doing so, as shown in the example below.

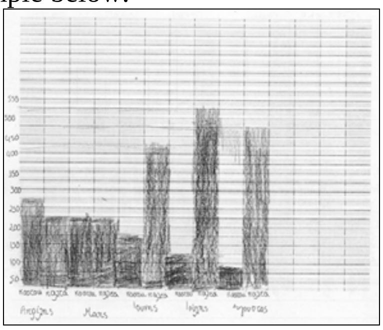

Figure 13. Example from difficulty 1

<u>Difficulty 2:</u> Students tend to believe that graphs can present only a small number of measurements (a couple of values). They have difficulty in realizing that it is possible to display the continuous variation of these quantities through the same graph, as shown in the example below.

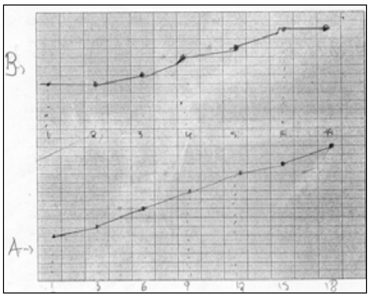

Figure 14. Example from difficulty 2

Difficulty 3: Children do not appreciate the importance of scaling the axes correctly, so as to make it possible to compare the quantities. They do not scale the axes in equal intervals, but according to the space they have to construct their graph, as shown in the example below.

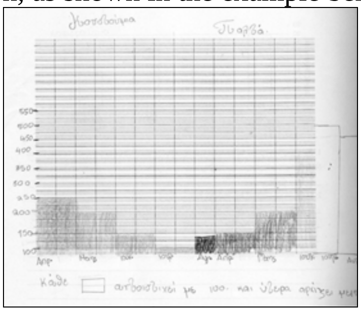

Figure 15. Example from difficulty 3

4.3. Comparing students' graphing achievement on pre-test, mid-test and post-test

Students' responses to all tasks were evaluated and categorized (false answer – score=0, correct answer – score=1). We used the Paired-Samples T-test to compare students' achievement on each task between pre-test, mid-test and post-test.

The mean score on each task and the results of the statistical analysis are presented in table 1:

Table 1. Paired-Samples T-Test

Task	mean score: pre-test	mean score: mid-test	mean score: post-test	T	df	Sig
1	0,34		0,66	-2,750	34	,009*
2	0,00		0,06	-1,435	34	,160
3		0,03	0,09	-1,435	34	,160
4		0,63	0,77	-1,406	34	,169

Table 1 shows that the mean score of students' achievement in all tasks was higher after the intervention program. However, the difference in students' achievement was statistically significant with $t_{(34)}$= -2,750 and a p-value of ,009 (<,05) only in the case of task 1. Students' achievement is also higher on constructing histograms (tasks 1 and 4), as compared to constructing line graphs (tasks 2 and 3).

We also used the Paired-Samples T-test to compare students' achievement between the total mean score on each test (pre-test, mid-test and post-test). A student's achievement on each test was the mean score of the graphing tasks. The results of this analysis are presented in table 2.

Table 2. Paired-Samples T-Test

	mean score: pre-test	mean score: mid-test	mean score: post-test	t	df	Sig
Data graphing	,171		,357	-3,404	34	,002*
		,328	,269	-1,871	34	,070

Table 2 shows that the difference of students' achievement between pre and post test is statistically significant, with $t_{(34)}$= -3,404 and a p-value of ,002 (<,05). There is no statistically significant difference between mid and post test, with $t_{(34)}$= -1,871 and a p-value of ,070 (>,05).

4.4. Interactions between data graphing and interpreting graphs

In order to identify any interactions between the skills of data graphing and interpreting graphs, we estimated the Pearson Correlation. Table 3 presents the correlation between the two skills on pre, mid and post test.

Table 3. Pearson Correlations and signifigance level

skill			Interpreting data from histograms	Interpreting data from line graphs	
Data graphing	Pre-test Achievement 1	Pearson	-.150	.341*	---
		df	35	35	---
		Sig.	.390	.045	---
	Mid-test Achievement 2	Pearson	---	---	.390*
		df	---	---	35
		Sig.	---	---	.02
	Post-test Achievement 3	Pearson	.082	.138	.072
		df	34	35	35

	Sig.	.647	.430	.680
Achievement 4	Pearson	.195	.371*	.090
	df	34	35	35
	Sig.	.268	.028	.608

Table 3 shows that before the intervention there was a statistically significant correlation between students' achievement on data graphing and interpreting data from line graphs, with $P_{(35)}$=,345 and a p-value=,045 (<,05). This interaction remains statistically significant after the formal teaching intervention, with $P_{(35)}$=,390 and a p-value=,02 (<,05) and after the science fair, with $P_{(34)}$=,195 and a p-value=,268 (<,05). There is no statistically significant correlation between data graphing and interpreting data from histograms. This might reflect the large difference in emphasis given to these two types of graphs in the context of formal education in Cyprus at these age levels.

5. Discussion

This study refers to a research program in which the Science Fair is used as an instructional activity aiming at the development of investigative skills in elementary school and the promotion of students' inquiry skills through a sequence of formal and non-formal activities.

The results presented in this article show that active participation in a science fair can lead to constructive development of graphing skills. Particularly, in this study we identified eight achievement levels on data graphing and several difficulties that hamper students' efforts to represent data using graphs. However, quantitative results showed that the students who participated in the research scored higher in all the tasks at the end of the intervention program. Their performances were better in tasks referring to the construction of histograms as compared to line graphs. The improvement in their performance was always significant after the whole intervention program. Finally, the results also demonstrate that the skill of constructing data graphs interacts with the skill of interpreting information from line graphs. This study also demonstrates that data graphing skills need to be taught systematically in elementary school in combination with other science investigation skills such as interpreting data.

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