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On the road to graphicacy: the learning of graphical representation systems

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ABSTRACT

This article examines the learning of different types of graphic information by subjects with different levels of education and knowledge of the content represented. Three levels of graphic information learning were distinguished (explicit, implicit and conceptual information processing) and two experiments conducted looking at graph and geographical map learning.

The graph study (experiment 1) examined the influence of the variables' numerical relationship structure on adolescent students with different levels of education and knowledge of social sciences and also assessed their proportional reasoning skills. The map study (experiment 2) looked at the learning of a geographical map studied spontaneously by secondary school and university students with different geographical knowledge (experts and novices) and also assessed their spatial skills..

The results of both studies show that graph and map learning performance improves with the subjects' educational level. The groups' differential performance varied according to the type of information involved (explicit, implicit or conceptual). The subjects' knowledge of the domain in question determined the level at which they processed the information. Verbal and superficial processing of graphic information were also found to predominate. This has important educational implications, suggesting the need for differential treatment in teaching of the different types of information. The results of the study also raise interesting issues regarding the type of expertise involved in learning graphic information: expertise related to the content represented, to knowledge of the syntax (graphicacy) and/or the system of knowledge graphically represented - spatial in the case of maps, numerical in the case of graphs.

INTRODUCTION

Following a period of neglect, the renewed interest of cognitive psychology in the learning and processing of images (e.g. Denis, 1991; de Vega *et al*., 1996; Richardson, 1999) is extremely relevant today in view of the high profile that iconic codes and diverse modes of graphic information are acquiring in our lives. Although the importance of images is increasing, iconic representations have always fulfilled a basic function in the conservation and transmission of knowledge in all cultures (Olson, 1994). Nevertheless, on the rare occasions that cognitive psychology has dealt with images, it has studied them as mere objects of processing, of perception, of memory and of learning rather than as social and cultural vehicles of representation.

In the same way that learning written language is not simply a process of decoding graphic signs, but rather a process of *literacy* that generates new forms of information processing (Olson, 1994), in the case of the processing of cultural systems of image-based representation we can speak of a new *graphicacy* that also involves new forms of processing in relation to the represented world. Following Olson (1994), when he states that "*The thought world is no longer simply the world, but rather the world as it is represented on paper",* we can say that the graphic "bombardment" to which we are submitted by the different multi-media communication channels makes *graphicacy* an essential skill for thinking about the world as it is represented in modern society.

However, despite the proliferation of images and the need for this new literacy, research on the use and understanding of images is quite limited, especially in comparison with research dealing with texts. Thus, not only has psychology shown a relative lack of interest in external systems of representation as against internal aspects of representation (Martí and Pozo, 2000), but it has also shown a considerable preference for certain external codes or systems over others. We are referring in particular to the disproportionate number of studies focusing on the learning of verbal or non-iconic systems or codes (e.g., writing, reading or numerical notation) in comparison with the amount of research carried out in the field of iconic codes or systems (e.g., drawings, graphs or maps). Cognitive psychology has focused mainly on the learning of verbal material (for example, studies on the comprehension of different types of texts, analysis of the strategies employed by subjects in order to understand or write a text, and so on), neglecting other types of material, such as those of an iconic or graphic nature.

The little research that has been done in this field is quite heterogeneous. This is due to the diversity of the graphic formats themselves -geographical maps, diagrams, illustrations and numerical graphs (for a review of classifications of graphic material, see Kosslyn, 1989; Postigo, 1998; Postigo and Pozo, 1999)- each with its own syntax and conventions. Nevertheless, a common finding of the studies of graphic material learning by subjects of different ages is the superficial way the material is approached. Students restrict themselves to reading data and processing specific aspects of the material and encounter problems when they have to go beyond this elementary level and interpret the information represented.

Out of the many different systems of iconic representation that exist, we have chosen in this article to concentrate on the learning of geographical maps and numerical graphs, two types of graphic material widely used in education and everyday life. By way of introduction, we shall present a brief review of the development of research in this field. We shall then put forward a hypothesis concerning the learning of this type of representation systems. Following this, we shall attempt to validate this hypothesis by means of two empirical studies.

We can differentiate three stages in the development cognitive research into the learning of maps and numerical graphs (Postigo, 1998; Postigo and Pozo, 2001). The first systematic approach by cognitive psychology to the study of maps was related to their use as a resource for the exploration of space. Maps were regarded as an instrument for acquiring quite specific spatial knowledge related to exploration or *navigation* in a particular environment devoid of all content other than what was required for locating elements within that environment. Thus, early studies compared learning a map with the spatial exploration of an environment or its description in a text (Freundschuh, 1991; Hirtle and Hudson, 1991; Taylor and Tversky, 1992; Thorndyke and Hayes-Roth, 1982). But maps were not studied as a cultural system of external representation with its own characteristics that could affect the way they were understood or processed.

In contrast to maps, graphs were regarded more as a goal in themselves than as a means of acquiring particular knowledge. However, the study of graphs was approached from a syntactic rather than a semantic standpoint within a perceptual perspective. Focusing on specific elements of graphs (for example, their system of symbols), it involved a prescriptive approach to the design of graphs (Kosslyn, 1985, 1989; MacKinley, 1987; White, 1984).

A second perspective in research concerning maps focused on an examination of maps as learning and/or memory material. Although maps were considered not as a cultural object, but as a merely physical object, interest was shown in maps as spatial representation. This group of studies is closely related to the well-known controversy in cognitive psychology regarding propositional versus image-based representations. Several authors have studied the processing of geographical maps in search of empirical support for Paivio's (1986) dual codification model. In fact, the early studies along these lines showed that processing maps requires dual -verbal and spatial- codification (Kulhavy, Lee and Caterino, 1985; Kulhavy, Stock, Peterson, Pridemore and Klein, 1992) and, in contrast to previous work, they focused on an analysis of the influence of different variables on the cognitive processing of maps.

Within the overall framework of these studies, some work raised doubts over the effectiveness of dual codification in map learning (Kinnear and Wood, 1987*;* Lanca and Kirby, 1995; Postigo and Pozo, 1996; Rossano and Hodgson, 1994). Using the customary methodology in such studies, whereby experimental instructions are used to try to influence the way in which subjects process maps, these studies showed that an approach combining the two types of processing (verbal and spatial) is not always the most effective, but that other variables may also affect the way in which maps are processed.

What appears to distinguish effective processing of a map is a selective or strategic approach to the information in it (Thorndyke and Stasz, 1980), as well as the possession of specific knowledge about the representations specifically contained in maps (e.g., Gilhooly et al., 1988; Ormrod, et al. 1988; Lowe, 1993; Postigo and Pozo, 1998). Indeed, one of the problems with most of the maps employed in studies comparing verbal with spatial processing is that they are fictitious maps whose structure and functions do not correspond to those of real geographical maps as systems of representation (Gilhooly et al., 1988;

Ormrod, et al. 1988; Van der Schee, 1988; Van der Schee, Dijk and Westrhenen, 1992). As pointed out above, the cognitive approach to maps, just as to other types of learning materials, has for too long ignored the particular nature of maps as external systems of representation with their own codes and epistemic functions. It is actually in the comprehension of these codes and functions that the specific features of the cognitive processing of maps reside.

In the same vein, research on the learning of graphs also resorted to a dichotomy, making a distinction between *local interpretation* and *global interpretation* of graphs, the former focusing on the location of specific values, the latter on finding and comparing trends (Carswell, Emery and Lonon, 1993; Guthrie, Weber and Kimmerly, 1993; Leinhardt *et al.*, 1990). Authors supporting this distinction point out that a global search is more difficult than a local search, since it requires a process of abstraction that the majority of students do not achieve. However, although the distinction between local and global interpretation has some empirical support, from a theoretical point of view the relationship between the two types of processing has not been resolved

This has resulted in a third approach, the most recent in this research field. Work on maps has increasingly focused on them as spatial representations with specific content determined to a large extent by their representational functions. Maps are no longer spatial objects, but rather external representations based on certain codes that subjects must acquire, so that making a mental representation based on a geographical map requires specific learning, a certain expertise in handling these codes and the semantic or conceptual knowledge linked to them. This semantic content poses the task of studying maps as more than simply retaining names and shapes, as it involves different degrees of processing or profundity. This approach, of which the present study is an example, suggests that map learning involves different levels of processing (Lowe, 1993, 1994, 1999, distinguishes between visual-spatial and semantic representation; Van der Schee, Dijk and Westrhenen, 1992 distinguish between reading, analysis and interpretation).

In line with this idea, some recent research considers global/local processing of a graph as a continuum, distinguishing different levels in the reading of a graph. These levels involve different degrees of elaboration in the study of a graph. Thus, Bertin (1983) distinguishes three levels of reading

– elementary, medium and overall – depending on the degree of detail of the information obtained. Schnotz (1993), on the other hand, proposes a hierarchy of information, distinguishing three orders of reading: first-, second- and third-order reading. Likewise, Postigo and Pozo (2001; also Postigo, 1998), maintain the existence of different levels of graphic information processing. We shall come back to this later.

Thus, according to these most recent studies, the learning of graphic representation systems involves the need to reconstruct the codes invented at the time for these representational functions. In their semiotic evolution, graphic representation systems, and in particular maps and numerical graphs (see, for example Olson, 1994; Wainer and Velleman, 2001), have become implicit, "concealing" information that was initially explicit through graphic marks or symbols, united by certain rules of graphic syntax, so that processing a geographical map or a graph involves decoding this information by learning the codes underlying it. But in addition to this syntactic component, a further requirement is knowledge about the represented content (for example, geographical, in the case of maps) that is involved in drawing inferences, which means higher-level interpretation. In other words, interpreting a map or a graph involves describing (saying what we see, observing its distribution or following its profile), but also explaining the reason for the configuration or profile, and the degree of elaboration will depend on the subject's knowledge. We therefore believe there is a certain similarity, at least on a first consideration, in the way these two types of graphic information are learned. This is manifested in different levels of processing which are described in more detail in the following section.

PROPOSED LEVELS OF ANALYSIS IN THE PROCESSING OF GRAPHIC INFORMATION

Since, in our view, the interpretation of graphic material involves going beyond the graphic representation of a map or a numerical graph, we propose distinguishing, along a continuum, different levels of depth in the way they are read or processed. Thus, based on the different types of information learning detected in a previous map study (Postigo and Pozo, 1998), we propose *three levels of graphic information processing*: explicit information processing, implicit information processing and conceptual information processing. Each of these three levels is based on different types of information provided by graphic material, and involves a greater degree of elaboration or depth in the learning of the material. The level on which the material is analysed depends on both subject factors (for example, cognitive development, prior knowledge or *graphicacy*) and task factors (the content of the material, its graphic structure, etc.), as well as the type of activities that accompany it (e.g. a text) which call for a particular type of interpretation of the graphic material. We shall describe each these levels, exemplifying them with the two types of graphic information we have mentioned (see Postigo, 1998, and Postigo and Pozo, 1999, 2001):

1.- The **processing of explicit information** involves a superficial reading focused on the elements of which it is comprised and identification of their different aspects - the title, number, name and type of variables of the phenomenon represented, their location and so on. Decoding it does not require the use of symbolic systems specific to the graphic material as external representations.

In a map, this level would focus on identifying the characteristics of the elements of which it is made up (number, type, name, location, etc.) - for example, finding out the number of churches or the names of villages in the province represented. In a graph, it would focus on identifying the different elements of the graph, for instance, the title, the number and name of the variables of the phenomenon represented and the different values of the variables - for example, finding out that Africa accounts for 10% of the world population represented in a graph.

2.- The **processing of implicit information** involves the interpretation of graphic material beyond the reading of isolated elements. It focuses on translating or decoding information that is present not explicitly, but via symbols.

This concealment or implicit representation of structural information nevertheless makes the processing of graphic material more demanding from a cognitive point of view, since the reader must have mastered these codes to be able to reconstruct its structure through more complex procedures than those employed in the previous type of processing. It requires of the subject a greater level of inference than the learning of explicit information, including information interpretation and decoding procedures involving the translation of the information from one code to another. Such procedures would form part of the *graphicacy* to which we referred earlier.

In regard to maps, this type of processing involves knowing how to interpret information present in different codes whose function is precisely to represent structural features of the map (orientation, relief, exact location, scales, etc.) that are concealed or implicit, through the use of certain symbols and syntactic rules which, within the cultural history of maps, have served to reduce the quantity of information that it is necessary to present explicitly in the map (Olson, 1994). Examples of this are the co-ordinates of latitude and longitude (to determine the location of any point) or the scale (in graphic or numerical format to determine distances). In graphs, this type of processing involves an interpretation beyond the reading of its values in isolation, identifying patterns and trends by establishing intravariable and intervariable relationships between these values. It also requires a degree of knowledge and mastery of the conventions of different types of graph, and of the decoding processes for legends and symbols.

3.- The **processing of conceptual information**, based to a large extent on the previous type of processing, focuses on the establishment of relationships between the different elements on the basis of an overall analysis of the structure of the information. This requires going beyond the explicit and implicit information provided and using prior knowledge to interpret the phenomenon represented.

In the case of a map, this involves establishing relationships and associations between its different elements, and applying geographical conceptual knowledge for making predictions and interpretations about the area represented - for example, inferring the type of economy from the location of certain places and the transport links between them. In the case of a graph, it involves establishing conceptual relationships based on analysing the graph's structure and using knowledge related to the content represented to produce interpretations, explanations or predictions about the phenomenon in the graph - for example, predicting the type of growth from a graph on world population.

These three levels of processing involve increasingly more elaborate study of the graphic information. However, although complete learning would imply reaching conceptual processing, the different levels should not be regarded as sequential, either in relation to the goals of the task (for example, identifying the capital city on a map involves only implicit processing in the form of decoding of the map's legend), or the traits of the subjects (for example, their cognitive development or prior knowledge). We believe that this analysis allows for greater flexibility and diversity in the ways of interpreting graphic information depending on various task and subject factors surrounding and determining the learning of such information.

With a view to validating our proposal, we shall present two experiments. In the first, we look at the learning of graphs, and in the second, the learning of a geographical map, by students of various ages drawn from different educational backgrounds.

The basic objective of the two experiments was to analyse the learning of graphic material according to the different types of information of which it is composed (explicit, implicit and conceptual). The aim was to see whether the subjects performed differently in regard to the three types of information and which type predominated in the way the material was approached by the different groups of subjects.

With regard to this latter aspect, we examined the influence of the type of education on learning, expecting differences in approach between the groups. Thus, as regards the influence of expertise on learning the different types of information in the material, expert subjects would be expected to perform better than other groups on general aspects (mainly conceptual information). We also expected differences between experts and novices in those aspects where domain knowledge plays an important part (for example, geographical knowledge in the case of maps). However, this group was not expected to perform better in regard to more specific or detailed information (explicit information). Conversely, the younger groups of subjects were expected to perform better, and to the same extent, in obtaining detailed information (explicit information) than in obtaining information requiring greater domain knowledge (implicit and conceptual information). In both experiments we also looked at the possible influence of other variables, such as mathematical and spatial skills.

EXPERIMENT 1

The main objective was to analyse the learning of various numerical graphs in subjects with different ages and educational backgrounds. Specifically, we aimed to study the extent to which the different types of information making up a graph (explicit, implicit and conceptual information) gave rise to different ways of processing of the material.

Another objective of this experiment was to explore the effects of the *structure of the numerical relationship* between the variables represented in a graph on its learning. As we have pointed out, we studied the type of processing involved in learning different graphs in subjects of various ages, analysing at the same time the influence of their type of educational and their proportional reasoning skills.

In looking at the structure of the relationship, we concentrated on two factors: the number of variables represented in the graph (we compared graphs with one and two variables) and the nature of these variables (graphs with nominal and ordinal variables). Graphs with a single variable would be expected to be learned more easily than graphs with two variables. Likewise, given that graphs with nominal variables present the information in an isolated way, compared to graphs with ordinal variables, which involve following and studying trends in the information, we expected the graphic representation of the nominal variables to be easier to interpret than that of ordinal variables

METHOD

Subjects. The sample was composed of 320 students divided into four groups of 80 subjects each, with the following mean ages: 12, 14, 16 (specialising in sciences) and 16 (specialising in arts). In turn, each of these four groups was subdivided into four subgroups according to the different experimental conditions.

Design. A 4 x 2 x 2 between-subjects factorial design was employed in which we varied the age-group and educational backgound (with four values: 12, 14, 16 (sciences) and 16 (arts)), the type of variables represented in the graph (with two values: nominal variable and ordinal variable) and the number of variables (with two values: one variable and two variables).

Procedure and materials. The task consisted of two stages: a study phase and an evaluation phase.

For the <u>study phase</u> we designed four different bar graphs with a geography content, combining the variables analysed (type and number of variables). The graphs used were as follows (see two examples in Figure 1):

1) Graph with one nominal variable (NO1): *Distribution of world population in 1994*.

2) Graph with one ordinal variable (OR1): *World population growth.*

3) Graph with two nominal variables (NO2): *Socioprofessional structure of the active population.*

4) Graph with two ordinal variables (OR2): *Trends in the active population in Spain by sectors.*

INSERT FIGURE 1 HERE

The four groups of subjects (12, 14 and 16 year-olds – sciences and arts) were divided into four subgroups according to the four experimental conditions, depending on the type of graph they were assigned to study. Subjects were asked to study the graphic information for 10 minutes, noting down their conclusions about the information so as to get them to process the information in depth. At the end of the study phase, the graphic information was taken away and the evaluation phase begun.

In the evaluation phase all subjects, regardless of their experimental condition, were given two tasks, with 35 minutes to carry them out: a learning questionnaire and a proportional reasoning questionnaire.

- *Learning questionnaire*: This included 12 multiple-choice items with three response options each. The items were designed in accordance with the different types of information in the graph (explicit information, implicit information and conceptual information), so that there are four items for each type of information.
- *Proportional reasoning questionnaire*: We administered an adapted form of the questionnaire designed by Pérez Echeverría (1990) comprising ten problems on the quantification of proportions.

Analysis Criteria. The marking criteria the questionnaires used in this experiment were as follows:

○ *Learning questionnaire* - Responses to the twelve items in this questionnaire were marked individually and scored as correct (with a score of 1) or incorrect (with a score of 0). They were then grouped according to the three types of information (explicit information, implicit information and conceptual information). The maximum score for each type of information was four points, with a maximum of twelve points for the whole questionnaire.

○ *Proportional reasoning questionnaire* - The total score for this questionnaire was obtained by adding up the number of problems correctly solved, the maximum score being ten points.

RESULTS

An analysis of variance (ANOVA 4 x 2 x 2 x 3) showed that the effect that the different types of information included in the graphs, in accordance with the distinction established, had on learning was ($F(2,608) = 49.14$; $p<0.0005$). According to a Tukey test ($p<0.05$), the subjects' performance on the explicit information items was significantly better than on the implicit information items. In turn, the learning of implicit information was significantly better than that of conceptual information (see Figure 2). This data pattern is in line with what was expected.

INSERT FIGURE 2 HERE

There was also a significant effect of the group variable ($F(3,304) = 12.61$; $p<0.0005$). Comparing the different groups with each other (see Figure 3), the Tukey test showed that the two groups of 16-year-olds (sciences and arts) performed significantly better than the two groups of younger adolescents (aged 12 and 14) in learning graphs, with no significant differences between the two groups of 16-year-olds ($p< 0.05$).

INSERT FIGURE 3 HERE

This confirms what was expected: the adolescents' graph learning performance improved with the subjects' age. However, the type of education was not found to have any influence on learning, which means that instruction in the content of the graphs had no effect on learning them. Nevertheless, given that interaction effects were observed among the main variables, analysing them will give us a better understanding of how education influences graph learning.

Thus, the analysis of variance indicates that the group x type of information interaction produces significant effects ($F(6,608) = 5.71$; $p< 0.0005$) so that the performance of the different groups varies as a function of the type of information requested. As Figure 4 shows, there are no differences between the various groups in the learning of explicit information, according to the Tukey test. On the other hand, in the learning of implicit information, the group of 16-year-olds (sciences) performed better than the other groups (16-arts, 14 and 12) ($p< 0.05$). In the learning of conceptual information, the only difference found was that the two groups of 16-year-olds (sciences and arts) and the group of 14-year-olds performed significantly better than the youngest group (aged 12) ($p< 0.05$), with no significant differences among the performances of the first three groups.

INSERT FIGURE 4 HERE

Thus, the learning of the different types of information (explicit, implicit and conceptual) present in a graph differed from one group of subjects to another. All the groups were equally oriented to learning explicit information, which is more superficial and detailed. The differences between the groups were found in the processing of implicit and conceptual information. In the case of implicit information, the differences reflected the influence of the type of education, since the sciences 16-year-olds performed significantly better not only than the younger students, but also than the arts students of the same age. A possible interpretation of this is that, in the specific case of implicit information, education in sciences (with its *graphicacy* component and/or greater mathematical training) has a positive influence on graphic information learning, whereas social sciences teaching (received by the arts group) does not favour the learning of graphs. This interpretation regarding the importance of expertise in *graphicacy* and/or mathematics is also supported by the fact that in the case of conceptual information (where the content plays an essential role), the arts 16-year-olds not only failed to perform better, but also do not differ in their performance from the sciences 16-year-olds or the 14-year-olds. This result also underlines the importance of the degree of difficulty of the different types of information, an aspect to which we shall refer in more detail, together with the type of expertise involved, in the final discussion.

With regard to the *numerical relation structure*, the analysis of variance (ANOVA 4 x 2 x 2 x 3) pointed to the characteristics of the variables represented in the graphs as being significant. In the first place, there was a type of variable effect ($F(1,304)= 7.11$; $p= 0.008$), with performance being significantly better in graphs with nominal variables (mean = 2.7) than in those with ordinal variables (mean = 2.5). There was also a number of variables effect ($F(1,304)= 5.41$; $p= 0.021$), with performance being better in graphs with one variable (mean = 2.7) than in graphs with two variables (mean = 2.5).

Finally, although subjects' *proportional reasoning*, as measured in this study, did not affect the relationship between learning and the structure of the numerical relationship of the different graphs (ANCOVA 4 x 2 x 2 x 3, with the proportional reasoning covariable), it should be underlined that this analysis found the relationship between proportional reasoning and graph learning to be significant (r = 0.32; $F(1,315) = 37.54$; $p<0.0005$). Thus, subjects with the best graph learning performance showed greater proportional reasoning ability, whereas those with poorer performances had lower proportional reasoning scores. In fact, the group with the highest proportional reasoning ability was that of the sciences 16-year-olds (mean = 7.91), which differed significantly from that of the arts 16-year-olds (mean = 6.42) ($t(158) = 2.71$; $p< 0.007$); both groups performed better than the two younger groups (aged 14 and 12) (means = 4.27 and 5.97, respectively).

EXPERIMENT 2

The objective of this experiment was to analyse geographical map learning as a function of the different types of information -explicit, implicit and conceptual information- of which the map is made up. Another aim was to see whether the different groups of subjects performed differently in map learning in regard to the three types of information and, if so, which one was predominant . In this experiment, in contrast to the previous one, the age range of the sample was extended to include university students taking different courses or with expertise in geography. Thus, for example, in principle, younger subjects would be expected to perform more poorly than older ones who had received more geography teaching.

Yet another objective of this experiment was to analyse the extent to which spatial variables (both of a general and a specific nature) mediate in geographical map learning. Insofar as the task of learning a map requires the manipulation of both external and internal spatial representations, we thought it would be useful to examine the extent to which the subject's spatial ability is involved. Thorndyke and Goldin (1983), in a study with subjects who were "good" and "poor" at map use, found that the good subjects performed significantly better in visual memory, visualisation and spatial orientation. They thus concluded that the differences found between the two groups in spatial learning derived from the differences in their ability to retain and manipulate spatial information. Although comprehensive research on this aspect would be necessary to ascertain which spatial skill factor or factors are involved in map learning, we distinguished two types of spatial skills in order to examine the extent to which a geographical map learning task requires *general spatial skills* or *specific spatial skills* appropriate to the task.

METHOD

Subjects. The sample consisted of 100 students divided into five groups with different ages and different levels of education and expertise in geography. Thus, there were five groups of 20 subjects each with the following characteristics: three groups of adolescents with mean ages of 12, 14 and 16 years, and two groups of university undergraduates studying psychology and geography, respectively, which constituted the groups of novice and expert subjects. Each of the five groups included the same number of subjects of each sex.

Materials. The materials used were a map, a questionnaire and spatial tasks.

- *Map.* A coloured geographical map (size: 29.5 x 21 cm) showing an area in the north-west of Spain (the Ancares valley in the west of León province) (for the characteristics of the map, see Postigo 1998 and Figure 5).

INSERT FIGURE 5 HERE

- *Questionnaire.* This included 18 multiple-choice items with three response options. These items were designed according to the different types of map information (explicit, implicit and conceptual information), so that there were six items for each type.

- *Spatial tasks.* We administered two types of spatial tasks, one of a specific nature – related to the map learning task – and another of a general nature to assess subjects' spatial skills.

a) Specific spatial skills: Space-perceptive test Situation-1 (SIT-1) (Seisdedos, 1990).

b) General spatial skills: Spatial factor (E) of the battery of Primary Mental Aptitudes (PMA) (Thurstone and Thurstone, 1941; 1989).

Procedure and design. The test comprised two phases: a study phase and an evaluation phase.

In the study phase we presented the subjects with instructions indicating that they had 30 minutes to study a map that would be given to them together with a sheet of paper for making notes.

They were also told about the second part of the test consisting in a series of questionnaires with items related to the map that they would have to answer with and without the map for reference.

The evaluation phase consisted in the administration of the questionnaires. The map and the note sheet were taken away and subjects were given the questionnaire with questions about explicit information in the map. After these questionnaires had been collected by the experimenter, the map and the questionnaire with items on implicit and conceptual information were given out. Finally, the specific (SIT-1) and general (PMA) spatial questionnaires were distributed.

The type of design used was a simple one with five independent groups (three groups of adolescents and two groups of university students).

Analysis Criteria. The marking criteria for each of the materials used were as follows.

○ Questionnaire: Answers to the eighteen items making up this questionnaire were marked individually and scored as correct (with a score of 1) or as incorrect (with a score of 0), the maximum score for each of the three types of information being six points, with a maximum of eighteen points for the whole questionnaire.

○ Spatial tasks

a) Specific spatial skills: the test Situations-1 was scored in accordance with the marking norms given in the manual (Seisdedos, 1990).

b) General spatial skills: as in the case of the previous test, the spatial factor (E) of the battery of Primary Mental Aptitudes (PMA) was scored according to the marking norms given in the manual (Thurstone, 1989).

RESULTS

Comparing the performance of the different age and education groups in regard to the different types of map information, the analysis of variance (ANOVA 5 x 3) showed a significant group variable effect, $F(4,95) = 17.38$ ($p < 0.0005$). As can be seen in Figure 6, map learning performance improved as subjects' age and educational level increased. Comparison of the means of the different groups shows three blocks of groups (12-; 14- and 16-year-olds; and the two groups of novice and expert undergraduates). Although the two older groups of adolescents (14- and 16-year-olds) performed significantly better than the 12-year-olds, the two groups of undergraduates (psychologists and geographers) performed significantly better than the three groups of adolescents (12-, 14- and 16-year-olds), with no significant differences between the two groups of university students ($p < 0.05$).

INSERT FIGURE 6 HERE

The analysis also showed a significant effect of the interaction group x type of item, $F(8,190) = 9.61$ ($p < 0.000$). Thus, the performance of the groups varied in a different way according to type of item or map information (see Figure 7). The groups of adolescents performed better on the explicit information items than on the implicit or conceptual information items. This pattern was reversed in the case of the geographers (experts), who obtained their best performance on the implicit and conceptual information items while performing very poorly on the explicit items. The psychologists group (novices), performed similarly on all three types of items, although they performed better in regard to implicit than explicit information, and, like the adolescents, gave their poorest performance on the conceptual information items.

INSERT FIGURE 7 HERE

The Tukey test showed that the psychologists and the 16-year-olds performed significantly better than the geographers on the explicit information items ($p < 0.05$). According to the Tukey test, the 16-year-olds performed better than the 12-year-olds on the implicit information items, the group of psychologists performed better than the 12- and 14-year-olds, and the geographers group performed significantly better than all the adolescent groups (12-, 14- and 16-year-olds) ($p < 0.05$). We therefore see, in regard to implicit information, a developmental tendency in which performance improves with increasing age and level of education. Finally, the Tukey test shows that while the psychologists group performed significantly better than the youngest adolescents (aged 12) on the conceptual information items ($p < 0.05$), the geographers performed significantly better on this type of information than all the other groups (12-, 14- and 16-year-olds and psychologists) ($p < 0.05$).

This result shows, therefore, that the performance of the different groups varies as a function of the type of map information requested, with three large groups being distinguishable: adolescents, novices and experts, focusing mainly on explicit, implicit and conceptual information, respectively, when faced with the task of learning a geographical map; the first group presents superficial processing, compared to a deeper processing of the material by the second and third groups.

Finally, it should be pointed out that the *spatial tasks* introduced subject variables whose influence we were interested in controlling to see whether they had any type of effect on map learning. These variables (PMA, SIT) were introduced as covariables in the covariance analysis (ANCOVA 5 x 3) whose results were compared with those of the previous analysis of variance (in which the effect of these variables was not taken into account). The results of the covariance analysis showed that the significant effects detected by the analysis of variance were maintained, leading us to think that it is not necessary to control the variables (covariables) we introduced in the design. In other words, in this study, the spatial factors of the subjects in our sample (as measured by the PMA E factor and SIT-1) did not appear to mediate in their geographical map learning performance.

DISCUSSION

As far as the main objective of this research is concerned, the results of both experiments reveal differential learning of the three types of information (explicit, implicit and conceptual) which, according to our analysis, are contained in the two systems of graphic representation – geographical maps and numerical graphs – that we have studied. In general, we found that subjects tend to focus on explicit, rather than implicit and conceptual, information. This predominance of verbal information processing is in line not only with our expectations, according to the hierarchy established between these processing levels, but also with the data obtained in other studies (for example, Curcio, 1987; Kinnear and Wood, 1987; Padilla *et al.* 1986; Postigo and Pozo, 1996, in press; Thorndyke and Stasz, 1980). Nevertheless, in our study, both in Experiment 1 and Experiment 2, we found this superficial processing to be characteristic only of the least educated subjects, in this case adolescents. Map learning and graph learning, however, differed from this pattern as regards the behaviour of the older adolescents in dealing with the graphs (Experiment 1) and the university students with the map (Experiment 2).

Together with this tendency to learn the verbal or explicit information in the map, in both experiments we also found that implicit information was processed better than conceptual information. This shows that in learning, subjects discriminated between the different types of information present in the two types of graphic material (maps and graphs), which confirms the theoretical relevance of the differentiation between the three levels of processing, as well as the hierarchical order we have established.

But this differential processing of the different types of information contained in a graphic representation was clearly influenced by education, with notable differences appearing between the groups studied. Thus, in geographical map learning (Experiment 2) we see how the groups differed with regard to the information they learned most effectively. Expert subjects (the geographers group), with a more global and meaningful approach to the map, showed better learning of implicit and conceptual information as against explicit information, in which they performed more poorly than the other groups, including the group with the same educational level (psychology undergraduates). With a totally different pattern, the three adolescent groups (12-, 14- and 16-year-olds), using techniques targeting specific and detailed information in the map, gave their best performance in regard to explicit information, and a poor performance in implicit and conceptual information. In contrast to these two patterns, the group of novices (psychologists), with more elaborate learning procedures than those of the adolescents, focused less than these groups on explicit information, presenting its best performance in regard to the implicit information in the map. However, although these subjects tended to learn conceptual information better than the adolescents (although they were significantly better only than the 12-year-olds), given their lack of domain knowledge, they performed poorly on conceptual information compared to the other undergraduates, who are experts in the domain of geography.

It could be said that the least educated subjects are capable of only extracting explicit verbal information from the map and have serious difficulties in processing information represented implicitly by means of the rules and codes characterising geographical maps as cultural systems of representation (as we saw in the introduction). Consequently, they found it difficult to extract the conceptual knowledge that can be derived from the map as a geographical representation. We can say, then, that the adolescents displayed quite limited levels of *graphicacy*, at least in the case of geographical maps, since they did not possess knowledge for decoding the map as a complex structured representation, with its own syntax, of a geographical space. On the other hand, the university students, both psychologists and geographers, did process the implicit information, but differed from each other in their capacity to draw conceptual inferences from this representation. It is precisely in regard to conceptual information that differences appear between expert and novice subjects in geographical map learning, as seen in the work of Gilhooly *et al.*, (1988). This is because what subjects see and can interpret in a map depends both on their study strategies and on their domain knowledge. Those with limited strategies can only describe the individual elements of the map, without a more elaborate analysis and interpretation of the phenomena represented in it. As Lowe (1993)has pointed out, the differences between experts and novices do not reside in the recall of literal information or the physical characteristics of the map, but rather in the interpretation or meaning subjects attribute to the different elements comprising it.

The pattern of results in relation to the learning of the different types of information in numerical graphs (Experiment 1) was quite similar in the different groups. There were no differences between the groups in regard to explicit information, since, as we have already mentioned, explicit information in graphs is that which is best learned by all of them. This result coincides with the findings of Bestgen (1980). In the case of implicit information, it is the eldest group of adolescents (aged 16) taking sciences that stands out: its performance on such tasks was better than all the other groups and of a similar level to its own performance on explicit graph information tasks. This result may be useful for training students in the use of graphs, as it is in learning implicit information that *graphicacy* and mathematical skills play the most crucial role. Finally, in the case of conceptual information, which constitutes the most complex level of graphic information processing, the two groups of 16-year-olds (sciences and arts) and the 14-year-olds performed better than the youngest group (12-year-olds).

Thus, instruction in the interpretation of these types of graphs should focus on the learning of implicit and conceptual information. On the other hand, it does not appear so necessary to focus teaching on explicit information in the graphs, at least in the age groups with which we worked. In the learning of implicit information, it seems that the relevant expertise would be not so much the knowledge subjects possess regarding the content of the graph –which would have more influence on conceptual learning, where there are no effects of education were found – as their knowledge about the different graph structures or formats, that is, knowledge of the syntax or conventions of graphs (*graphicacy*).

Similarly, we examined the extent to which subjects' *spatial skills* might intervene in geographical map learning. We considered whether the task of learning a geographical map may require general and/or specific spatial skills according to the task. The results indicate that subjects' spatial skills, at least as measured in our study, are not a mediating variable in map learning performance. In other words, the characteristics of the subjects in regard to these two variables (general and specific spatial skills), as assessed in this study, do not appear to mediate in map learning. *Graphicacy* may depend more on the learning of certain cultural systems of representation, through education, than on the existence of differential spatial skills or abilities. Although undoubtedly at higher levels of expertise, we would expect an effect of these variables. Mastery of cultural systems of graphic representation, as occurs with similar systems (literacy, numeracy, etc.), may not require special abilities, possibly because the *cultural design* of these systems is restricted by the capacities of the human cognitive system itself (Pozo, 2001).

The data from our study suggest, on the other hand, the need to examine more thoroughly the differential effect of education on this graphicacy. This leads us to a final reflection on the types of knowledge or expertise involved in the learning of the graphic representation systems analysed in this study. In such learning, we can differentiate three types of expertise: (a) mastery of graphic representations as such, which we have studied here in terms of *graphicacy*, and which would correspond essentially to the processing of implicit information; (b) specific knowledge of the conceptual domain represented, i.e. the processing of conceptual information; and (c) mastery of the knowledge system graphically represented - spatial in the case of maps and numerical in the case of graphs. Our study supports the relevance and importance of the two first types of knowledge, while the effects of numerical and/or spatial skills are less clear. At all events, there is a need for studies that specifically control and compare these different types of expertise. As we have already said, we believe these should focus on analysing the cognitive processing of graphic representation systems as objects not only with a representational function, but also with a cultural history.

REFERENCES

Bertin, J. (1983). *Semiology of graphics*. Madison: Univ. of Wisconsin Press.

Bestgen, B. (1980). Making and interpreting graphs and tables: results and implications from National Assessment. *Arithmetic Teacher,* (December), 26-29.

Carswell, C.M.; Emery, C. & Lonon, A.M. (1993). Stimulus complexity and information integration in the spontaneous interpretation of line graphs. *Applied Cognitive Psychology, 7*, 341-357.

Curcio, F.R. (1987). Comprehension of mathematical relationships expressed in graphs. *Journal for Research in Mathematics Education, 18* (5), 382-393.

Denis, M. (1991) *Image and cognition*. London: Harvester Wheatsheaf.

Van Dijk, H.; Van der Schee, J.; Trimp, H. & Van der Zijpp,T. (1994). Map skills and geographical knowledge. *International Research in Geographical and Environmental Education*, *3* (1), 68-81.

Freundschuh, S.M. (1991). The effect of the pattern of the environment on spatial Knowledge acquisition. In: D.M. Mark & A.V. Frank (Eds.) *Cognitive and linguistic aspects of geographic space*.(pp.167-183) London: Kluwer Academic Publisher.

Gilhooly, K.J.; Wood,M.; Kinnear, P.R. & Green, C. (1988). Skill in map reading and memory for maps. *Quarterly Journal of Experimental Psychology Human Experimental Psychology*, *40* (1 Sect.A): 87-107.

Gobbo, C. (1994). On children's understanding of an economic concept: the role of graphics in evaluation. In: W. Schnotz & R.W. Kulhavy (Eds.) *Comprehension of graphics* (pp. 227-251). Amsterdam: North-Holland

Guthrie, J.T.; Weber, S. & Kimmerly, N. (1993). Searching documents: cognitive processes and deficits in understanding graphs, tables and illustrations. *Contemporary Educational Psychology, 18*, 186-221.

Hirtle, S.C. & Hudson, J. (1992). Acquisition of spatial knowledge for routes. *Journal of Environmental Psychology*, *11*(4), 335-347.

Kinnear, P.R. & Wood, M. (1987). Memory for topographic contour maps. *British Journal of Psychology*, *78*(3), 395-402.

Kirby, J.R. (1994). Comprehending and using maps: are there two modes of map processing?. In: W. Schnotz & R.W. Kulhavy (Eds.) *Comprehension of graphics* (pp. 63-77). Amsterdam: North-Holland.

Kirby, J.R. & Schofield, N.J. (1991). Spatial cognition: the case of map comprehension. In: M.G. Evans (Ed.) *Learning and teaching cognitive skills* (pp.107-123).Melbourne: ACER.

Kosslyn, S.M. (1985). Graphics and human information processing. A review of five books. *Journal of American Statistical Association*, 80 (391), 499-512.

Kosslyn, S.M. (1989). Understanding charts and graphs *Applied Cognitive Psychology*, 3, 185-226.

Kulhavy, R.W.; Lee, J.B. & Caterino, L.C. (1985). Conjoint retention of maps and related discourse. *Contemporary Educational Psychology*, *10*, 28-37.

Kulhavy, R.W.; Stock, W.A.; Peterson, S.E.; Pridemore, D.R. & Klein, J.D. (1992). Using maps to retrieve text: a test of conjoint retention. *Contemporary Educational Psychology, 17,* 56-70.

Lanca, M. & Kirby, J.R: (1995) Verbal and spatial processes in map learning. *Journal of Cartographic Perspectives*, *21*, 3-25.

Leinhardt, G.; Zaslavsky, O. & Stein, M.K. (1990). Functions, graphs, and graphing: tasks, learning and teaching. *Review of Educational Research*, 60 (1), 1-64.

Lowe, R.K. (1993). Constructing a mental representation from an abstract technical diagram. *Learning and Instruction*, 3, 157-179.

Lowe, R.K. (1994). Domain-specific constrains on conceptual change in knowledge acquisition from diagrams. Paper presented at *the Conceptual Change Symposium*, Jena, Germany.

Lowe, R.K. (1999). Constraints on the effectiveness of diagrams as resources for conceptual change. In: W. Schnotz; S. Vosniadou and M. Carretero (Eds.) *New perspectives on conceptual change*. London: Elsevier (pp. 223-245).

Martí, E. & Pozo, J.I. (2000). Más allá de las representaciones mentales: la adquisición de los sistemas externos de representación. *Infancia y Aprendizaje*, *90*, 11-30.

Olson, D. (1994) *The world on paper*. Cambridge: Cambridge University Press.

Ormrod, J.E.; Ormrod, R.K.; Wagner, E.D, y McCallin, R. (1988). Reconceptualizing map learning. *American Journal of Psychology, 101*, (3), 425-433.

Padilla, M.J.; McKenzie, D.L. & Shaw, E.L. (1986). An examination of the line graphing ability of students in grades seven through twelve. *School Science and Mathematics,* 86 (1), January, 20-26.

Paivio, A. (1986). *Mental representations: a dual coding approach*. New York: Oxford University Press.

Pérez Echeverría, M.P. (1990) *La psicología del razonamiento probabilístico*. Madrid: Servicio de Publicaciones de la Universidad Autónoma de Madrid.

Postigo, Y. (1998). *El aprendizaje de la información gráfica: mapas geográficos y gráficas*. Doctoral thesis. Facultad de Psicología. Universidad Autónoma de Madrid.

Postigo, Y. & Pozo, J.I. (1996). Codificación de mapas geográficos: diferencias entre expertos y novatos en el aprendizaje de distintos tipos de información. *Cognitiva*, *8* (1), 3-24.

Postigo, Y. & Pozo, J.I. (1998). The learning of a geographical map by experts and novices. *Educational Psychology*, 18 (1), 65-80.

Postigo Y. & Pozo, J.I. (1999). Hacia una nueva alfabetización: el aprendizaje de información gráfica. In: J.I. Pozo & C. Monereo (Eds*) El aprendizaje estratégico*.(pp. 251-271). Madrid: Santillana.

Postigo Y. & Pozo, J.I. (2001). When a graph is worth a thousand data: graph interpretation by adolescent students. *9th European Conference for Research on Learning and Instruction*, (pp. 245)

Pozo, J.I. (2001) *Humana mente. El mundo, la conciencia y la carne*. Madrid: Morata.

Richardson, J.T. (1999). *Imagery*. Hove: The Psychology Press.

Rossano, M.J. & Hodgson, S.L. (1994). The process of learning from small-scale maps. *Applied Cognitive Psychology*, 8, 565-582.

Van der Schee, J.A. (1988). Thinking geography with maps. In: R. Gerber & J. Lidstone (Eds.) *Developing skills and geography teaching*. (pp.76-79). Brisbane: Skills in Geographical Education Symposium.

Van der Schee, J.A.; Van Dijk, H. & Van Westrhenen, H. (1992). Geographical procedural knowledge and map skills. In: H. Shrettenbrunner & J. Van Westrhenen (Eds.) *Empirical research and geography teaching*. Amsterdam: Centrum Voor Educatieve Geografies Vrije Universiteit Amsterdam.

Schnotz, W. (1993). Understanding Logical Pictures. Friedrich-Schiller-University of Jena, Department of Educational Psychology: *Research Report 1*.

Seisdedos, N. (1990). *Situación-1: test espacio-perceptivo*. Ediciones TEA.

Taylor, H.A. & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language*, *31*(2), 261-292.

Thorndyke, P.W. & Goldin, (1983). Spatial learning and reasoning skill. In: Pick, & Acredolo (Eds.) *Spatial orientation: theory, research and application.* New York: Plenum Press.

Thorndyke, P.W. & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, *14*(4): 560-589.

Thorndyke, P.W. & Stasz, C. (1980). Individual differences in procedures for knowledge acquisition from maps. *Cognitive Psychology, 12*, 137-175.

Thurstone, Th.G. (1941). Primary Mental Abilities of children.. *Educational and Psychological Measurement. 1*, 105-116.

Thurstone, Th. G. (1989). *Aptitudes Mentales Primarias*. Ediciones TEA.

De Vega, M.; Intons-Peterson, M.J.; Denis, M. & Marschark, M. (Eds.) (1996). *Models of visuospatial cognition*. New York: Oxford University Press.

Wainer, H. & Velleman, P.F. (2001) Statistical graphics: mapping the pathways of science. *Annual Review of Psychology*, 52, 305-335.

White, J.V. (1984). *Using charts and graphs. 1000 ideas for visual persuasion*. New York: R.R. Bowker Company.

Figure 1- *Graphs NO1 and OR2 used in Experiment 1*

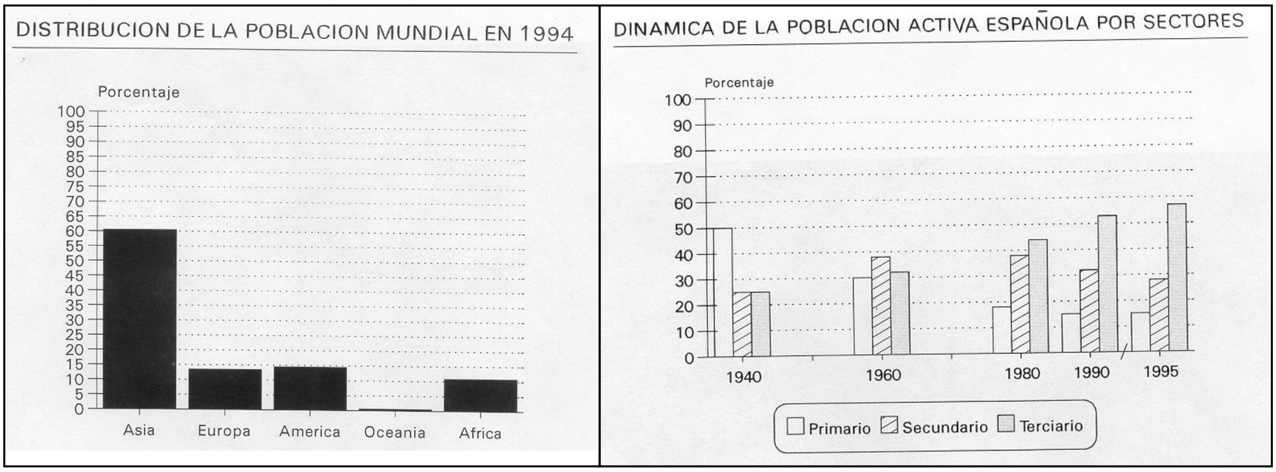

FIGURE 2- *Mean achievement by type of item (Experiment 1)*

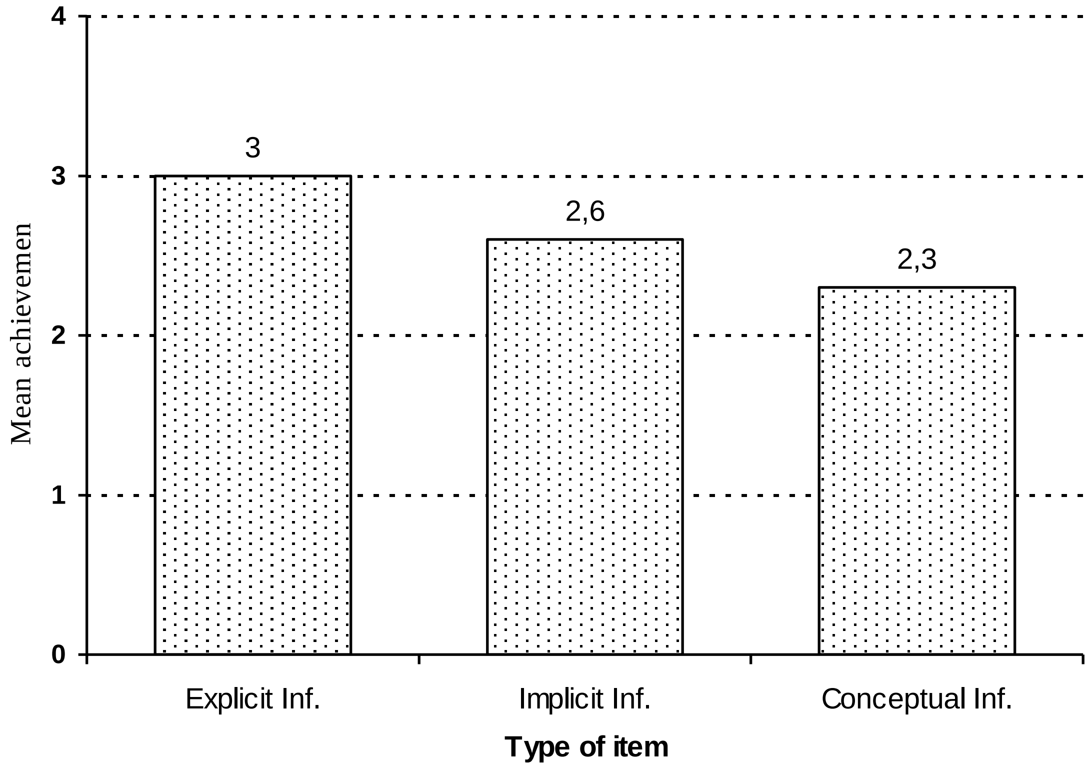

FIGURE 3- ***Mean achievement by group(Experiment 1)***

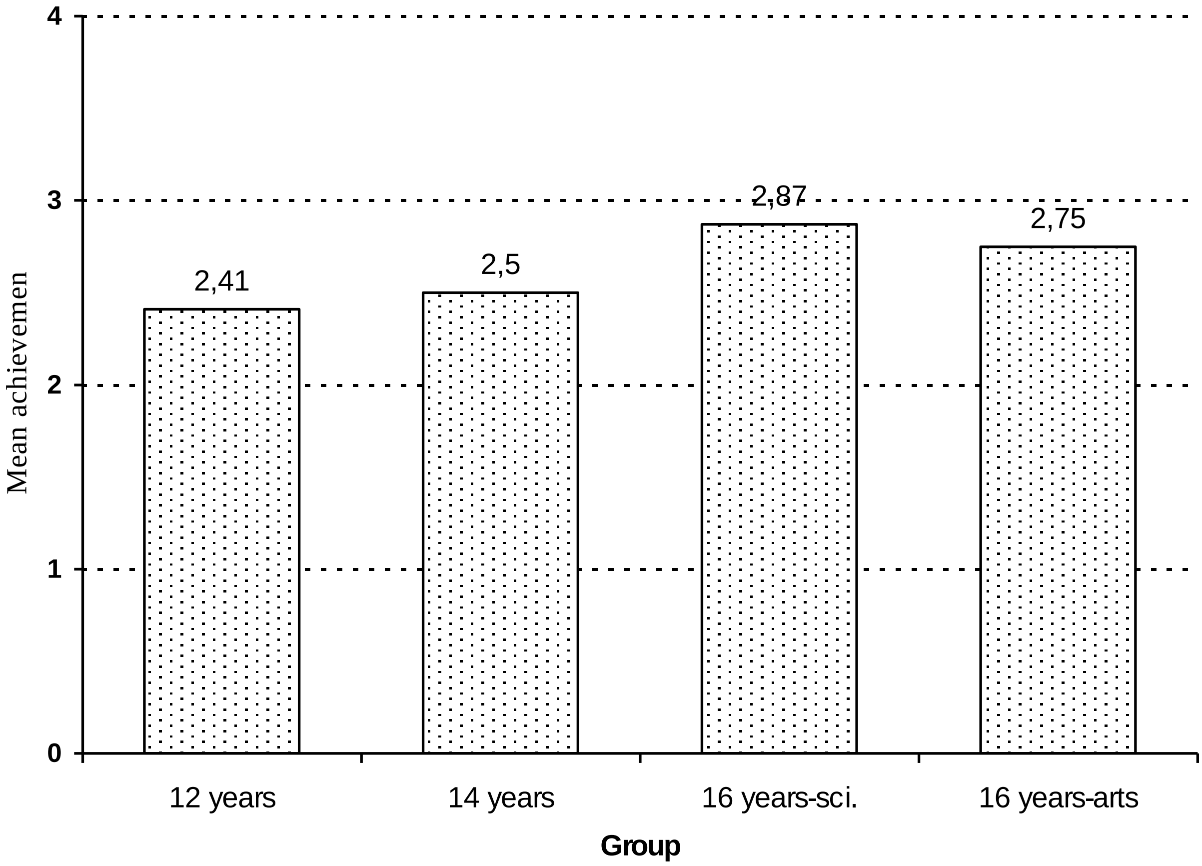

FIGURE 4- ***Mean achievement for the interaction group by type of item (Experiment 1)***

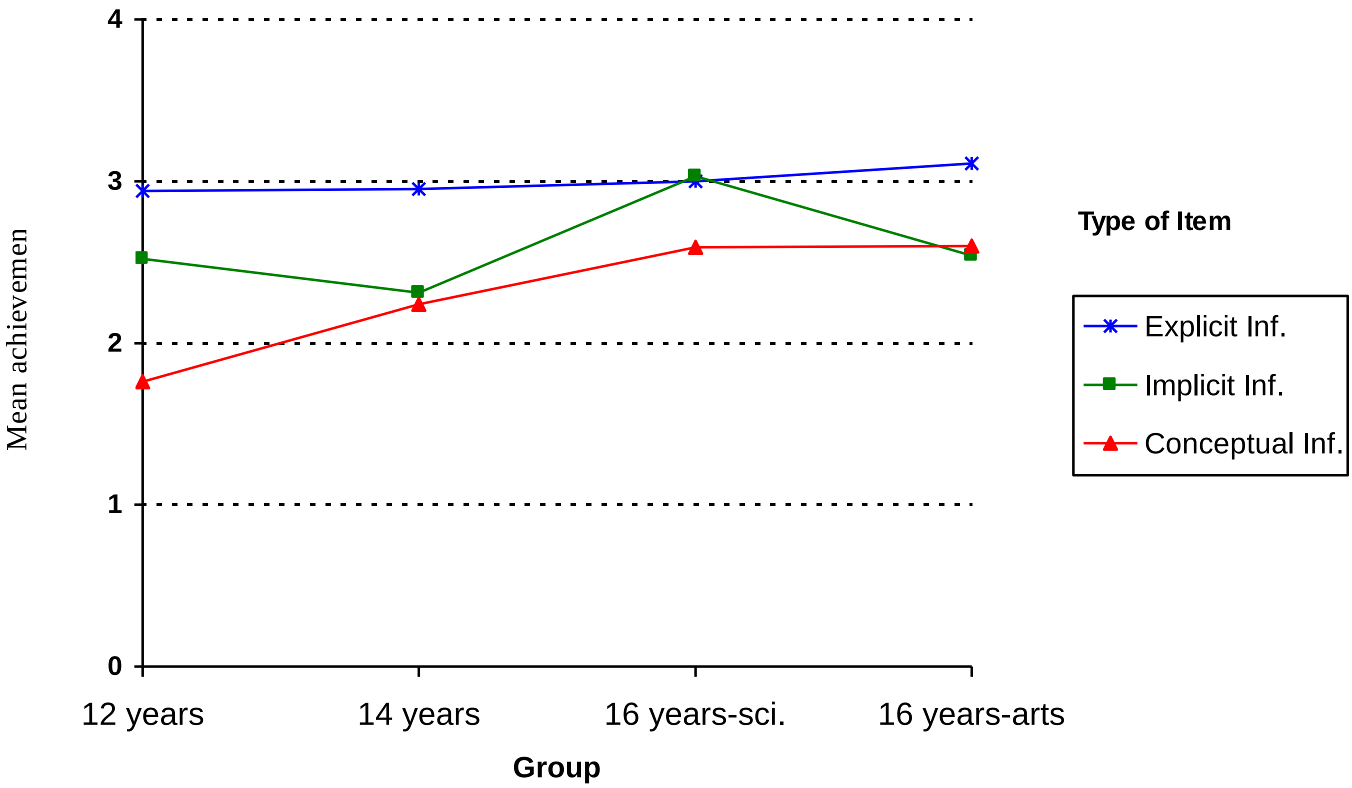

FIGURE 5- Mean achievement by group(Experiment 2)

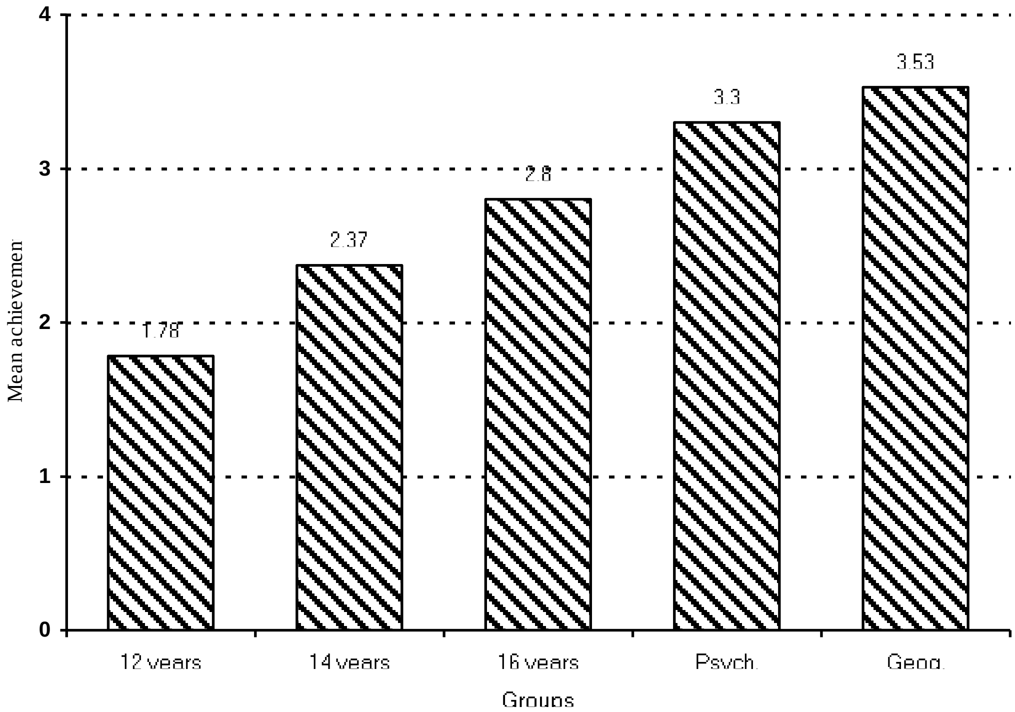

FIGURE 6- *Mean achievement for the interaction group by type of item* (Experiment 2)