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The Transformation of Natural to Geometrical Concepts, Concerning Children 5-7 Years Old. The Case of Measuring Surfaces

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SUMMARY *The aim of this research is to investigate the potentialities of teaching the concept of measuring surfaces to children of early school ages. The subjects of our research use the strategy of covering the measured surface. This strategy develops some meanings coming from mathematical tradition and psychological research. 131 subjects with the same social characteristics participated in the research process. We classified the children by three level ages (average ages 5.8, 6.9 and 7.5 years old). For every age level we separated the children into two groups, a control group and an experimental one. With the children of the experimental group we used material that was socially significant. Children had to choose from a group of different sized shapes appropriate for the covering of the surface. The results of the research showed supremacy of the experimental group over the children of the control group. Moreover, there are indications about the potentiality of teaching the measurement of area earlier than suggested by research based on a Piaget theoretical context.*

RESUME *L'objectif de cette recherche est d'étudier la possibilité d'enseigner le concept de mesure des surfaces à des jeunes enfants. Dans notre recherche, les sujets ont eu à faire à des surfaces mesurées. Cette stratégie développe certaines significations provenant de la tradition mathématique et de la recherche psychologique. 131 sujets, présentant les mêmes caractéristiques sociales, ont participé à la recherche. Les enfants ont été rassemblés en trois groupes par niveau d'âge (5.8, 6.9 et 7.5 ans). Pour chacun des niveaux, les enfants ont été répartis en deux groupes, un groupe contrôle et un groupe expérimental. Pour le groupe expérimental, nous avons utilisé un matériel significatif socialement. Les enfants devaient choisir, parmi des formes de différente taille, les formes pertinentes pour couvrir une surface. Les résultats de la recherche ont montré la supériorité du groupe expérimental sur le groupe contrôle. De plus, ils ont indiqué certaines façons d'enseigner la mesure des surfaces à un âge plus précoce que ce qui était suggéré par les travaux piagétiens.*

ZUSAMMENFASSUNG *Ziel der vorliegenden Forschungsarbeit ist die Untersuchung von Möglichkeiten, Kindern im frühen Schulalter Konzepte der Oberflächenmessung zu vermitteln. Die Versuchspersonen benutzen die Strategie der Umhüllung der zu messenden Oberfläche. Diese Strategie macht sich sowohl Elemente historisch früherer Stadien der Oberflächenmessung als auch Ergebnisse lernpsychologischer Forschung zunutze. An der Untersuchung nahmen 131 Versuchspersonen mit vergleichbaren sozialen Merkmalen teil. Die Kinder wurden in drei Altersgruppen unterteilt, mit Durchschnittsalter 5.8 Jahre, 6.9 Jahre und 7.5 Jahre. Jede Altersgruppe wurde dabei in zwei Untergruppen geteilt, eine Versuchs- und eine Kontrollgruppe. Bei der Arbeit mit der Versuchsgruppe wurde sozial*

signifikantes Material eingesetzt. Aufgabe der Kinder war es, aus einem Angebot an Formen unterschiedlicher Größenordnungen für die Umhüllung einer Oberfläche geeignete Form auszuwählen. Die Ergebnisse zeigen eine Überlegenheit in der Aufgabenbewältigung seitens der Kinder der Versuchsgruppe. Darüber hinaus ergeben sich Hinweise auf die Möglichkeit, die Messung von Oberflächen bereits früher als im Kontext einer Piaget-orientierten Didaktik vorgeschlagen zum Unterrichtsgegenstand zu machen.

RESUMEN Objetivo de la presente investigación es examinar las posibilidades de la enseñanza del concepto de medición de superficies en los primeros años escolares. Los sujetos de nuestra investigación usan la estrategia del recubrimiento de la superficie por medir. Ese proceso incorpora elementos tanto de la tradición matemática como de la investigación psicológica.. En nuestra investigación participan 131 sujetos de las mismas características sociales. Clasificamos los niños en tres niveles de edad (el promedio de edad de cada grupo era : 5.8, 6.9, 7.5). En cada nivel de edad dividimos a los niños en dos grupos: el experimental y el grupo control. Con los niños del grupo experimental usamos material socialmente significativo. Los niños debían elegir, entre un conjunto de formas de diferentes tamaños, los adecuados para el recubrimiento de la superficie. Los resultados de la investigación indicaron una superioridad de los niños del grupo experimental en la tarea. Paralelamente, aparecen indicaciones sobre la posibilidad de llevar a cabo la enseñanza de la medición de superficies en edades más tempranas a las que se proponen en las investigaciones basadas en la teoría de Piaget.

Keywords: Early childhood education; Geometry; Area; Concept; Measurement.

The Theoretical Framework

Many researchers who have dealt with the measurement of geometrical quantities (length, surface, etc.) generally represent two different searching aspects (Nunes et al., 1991).

The first one reflects the spirit of J. Piaget and his collaborators' research. According to Piaget's aspect there is no special interest in the effect of social contexts on the appropriation of mathematical concepts. The interest of these researches mainly focuses on logical-mathematical variables, which emphasise the acquisition of some special abilities, such as the one of measurement and more specifically the measurement of surfaces. The latter composes the main interest of our research.

The second searching aspect is expressed by the theoretical work of psychologists, like Vygotsky and Luria, who place stress on the analysis of the measuring procedure, which reflects the social dimension of the development of cognitive abilities.

In the next pages we will try to present, briefly, researches which reflect the above searching aspects and how this approach the procedure of measuring surfaces in the early childhood education.

1. The concept of measurement according to the framework of Piaget and the post-piagetian perspectives

The ability of measuring, in piagetian researches is ascertained by the comparison of two quantities. According to Piaget and his collaborators "measure is to take out of a whole an element, taken as a unit, and to transpose this unit on the remainder of a whole: measurement is therefore a synthesis of *sub-division* (of the whole) and *change of position* (of the selected unit)" (Piaget et al. 1960, p. 3. The comments in the brackets and the italics belong to the writers of this article). This procedure, although it may

seem simple at the stage of the final equilibration, is in fact a result of a complex genetic process.

The acquisition of the measuring concept, in the piagetian theoretical context, will be built at the stage of a child's intellectual development, which is characterised by the use of a mediated measuring tool. It concerns children of 7+ ages, and a distinctive characteristic of this stage is an operational use of the measuring procedure which is expressed by general logical operations, like for example: if A=B and B=C, then A=C.

The aim of Piaget and his collaborator's experiments (Piaget et al., 1960, p. 261-301) is to examine the conservation of the area concept with children in the early childhood education. In order to ascertain the possibility of the area concept acquisition the third axiom of Euclid is used as a criterion. According to this, when we subtract equal parts, e.g. $A_1=A_2$, out of equal areas, e.g. $B_1=B_2$, then the areas which remain are equal, that is; $A_1'=B_1-A_1=B_2-A_2=A_2'$. A fundamental criterion for this ascertainment is their potentiality to invert the operations, which take place with the surfaces. In Piaget's experiments what is examined, is how an operation like $A_1'=B_1-A_1$ can successfully lead us through reversibility to the mental operation of $A_1'+A_1=B_1$. So in order to investigate the conservation of the surface concept the operation of subtracting surfaces is selected ($A_1'=B_1-A_1=B_2-A_2=A_2'$). In this way, the experimental outline is absolutely placed in the piagetian theoretical model (Piaget et al., 1960, pp. 261-301).

There are a large number of experimental facts, which show that children who begin school, don't have such limited abilities concerning mathematical concepts, such as, the concept of number, the conservation of length, volume, measurement etc., as Piaget claims (Carpenter, 1975; Anderson & Cuneo, 1978; Light & Gilmour, 1983; Resnick, 1983; Donaldson, 1991; Hughes, 1986; Pepper & Hunting, 1998). These researchers question strongly, whether Piaget's experiments of conservation, indeed investigate what they claim to. One first question is, whether children's failure in these experiments is due to mental limitations or failing to understand the experimental situations (Hughes, 1986). Donaldson (1991) referring to her collaborators' experiments, similar to those of Piaget, discovered that children answered different questions from those made by the researchers. Very often, they fail to understand what the experimentalist asks them, and they don't seem to understand the meaning of the language. A second remark has to do with the planning of the experiment and whether the experimental material seems interesting to the child. In this way, when Piaget's experiments change form and the way they are planned seems appealing to the child, then the results of success are significant. When, for instance, the concept of measurement is dictated by the needs of the experimental situation, then in this case the specific concept appears earlier in young children's thought than Piaget and his collaborators concluded (Carpenter, 1975). Furthermore, Piaget downgrades the significance of social variables on the cognitive development of an individual. He believes, that one's mental development results from his action on the environment and the inward acceptance of this action. In this way, the piagetian model of learning is based on the relation between the one who learns and the object being taught and downgrades the exchanges, between a child and the environment.

When Piaget's conservation experiments are carried out in a social interaction frame, children respond successfully. This gives us a significant indication, that the process of social-teaching interactions is the cause of the cognitive development of the subjects (Doise & Mugny, 1981; Perret-Clermont, 1986).

The results of the piagetian aspect, are impressed on the curriculum of early childhood learning, where teaching mathematical concepts is limited to dealing with specific objects, their grouping and ordering, according to certain characteristics (colour, size, shape etc.). For example, teaching the measurement of lengths and surfaces by the use of different units of measurement is out of the didactic interests since children haven't constructed yet, according to the piagetian model, the concept

of conservation. That's how Piaget's theory seems to be "conservative", concerning pedagogic suggestion, as it stresses more the difficulties that are encountered in every learning stage rather than their capabilities.

Further on, we will refer to the pedagogical and teaching interest that the post-piagetian perspectives present.

2. *Towards a pedagogic dealing with the measurement of area. The process of forming units of measurement*

According to Freudenthal (1983), it would be a serious omission not to place the area concept in a mathematical context frame relative to the concept of measurement. The measuring procedure varies, according to the needs, which create it, the level of accuracy and generality that we want to give it, and of course is relative to the cognitive level of the people who deal with it. For the age scale which interests us here, measurement is the quantitative definition of a natural quantity, which is found compared with an appropriate size used as a unit. The measurement result is a number, which expresses the analogy between the measurement size and the invariable size, which forms the unit of measurement (Sydenham, 1979).

The appropriation of the measuring operation presupposes two distinctive characteristics (Nunes et al., 1996):

- The first one has to do with the introduction of a common mediator, like for example the ruler for the comparison of two lengths. The conclusions here have usually the following form: If A=B and B=C, then A=C, or, if A>B and B>C, then A>C. In these cases comparisons are indirect, and are made with the combination of two different comparisons (for instance A=B, B=C), where the compared quantities A and C are compared with the B quantity (which is here a kind of measure). Researches about the conception of the measurement characteristic, by children at the ages of 5 and 6, showed that they generally responded successfully to the relevant tasks (Nunes et al., 1996).
- The second characteristic of the measurement procedure has to do with the appropriation of unit of measurement. This fact offers a great number of possibilities to the process of measurement. The previous transitive inferences form a general precondition, necessary for a successful measurement. With the use of the measuring unit though, we're not simply restricted to transitive inference, but we can pronounce for example upon how many times the A quantity is bigger than the C quantity.

Researches by Wheatley et al. (1996) and Reynolds et al. (1996), bring out the opinion that the function of unitising, is not restricted to arithmetic but can be also observed equally in geometrical activities. What they claim is that the construction of a unit surface is a fundamental component of constructing the area concept in children's minds. The covering process of a surface is considered (Reynolds et al., 1996) to be very creative in the procedure of forming units of measurement. A basic element for the construction of units, during the realisation of a covering task, is on the one hand the construction of a model-unit and on the other hand the use of this unit in order to cover the measured surface. The activity suggested to the subjects of our research uses the process of *covering*. This effort embodies elements from the historical evolution of the surface measurement procedure, and discoveries by psychological research about learning. In Euclidean Geometry measurement preconditions the comparison of sizes, which is fulfilled with the *principal of covering*. This means covering the measured surface with another surface or the unit surface. In this approach we're not so interested in the accurate arithmetical results, but what is emphasised is the development procedure of this activity. Furthermore, we made sure that the experimental

material, as well as the planning of the experimental group's activity was socially significant, so as to make some sense to the children. A task can be characterised as socially significant, when the cognitive abilities required for the successful response to it, are derived from social activities or situations, with which children are familiar and can understand. The idea of using the socially marking material, derives from the theoretical work of researchers, such as Doise & Mugny (1981), de Paolis & Mugny (1985) and Perret-Clermont (1986), who have proved the positive contribution of social significance, and its causal factor to the cognitive evolution of the subjects.

We assumed that children, using the strategy of covering, at a surface measuring task, with a socially significant material, will respond better to this task, than children who try to solve a similar problem, using material of no social significance.

Method

Subjects

One hundred and thirty-one subjects participated in the research process attending schools in Patras (Greece) located in regions with the same local characteristics. We classified the children by 3 age levels. We had 35 subjects in the first level (average age 5.8 years, standard deviation 2.8 months), 42 in the second (average age 6.9 years, standard deviation 3.1 months) and 54 in the third one (average age 7.5 years, standard deviation 2.6 months). The selection of the subjects was done by stratification random sampling. The children's parents had no special education in mathematics or science. For every age level we separated the children into 2 groups, a control group and an experimental one.

The teaching materials

With the pupils of the control group we used 3 sets of 4 rectangular parallelepipeds of different dimensions (10cm x 4cm x 1cm, 12cm x 6cm x 1cm, and 14cm x 7cm x 1cm). By placing the medium sized shapes (12cm x 6cm x 1cm), side by side, we cover a rectangular cardboard surface (Figure 1).

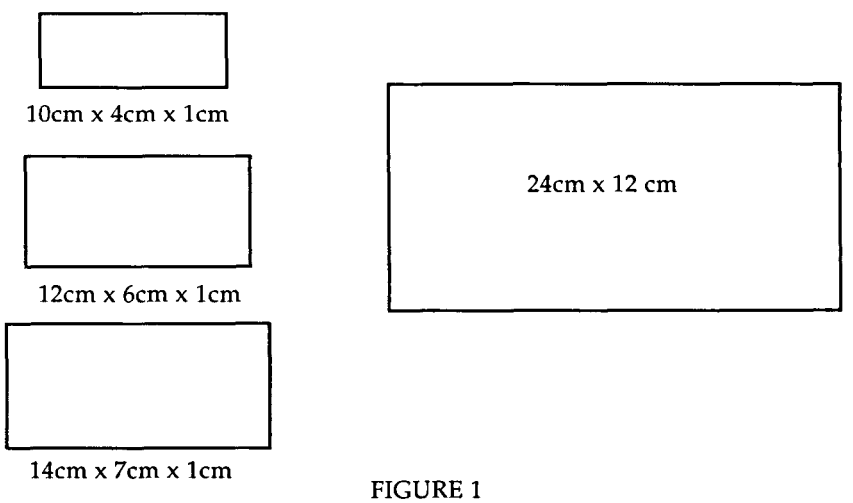

FIGURE 1

With the pupils of the experimental group used 12 wooden figures, of equal to the previous ones dimensions, which had the form of cars, without the rectangular shape of their base being transformed. By the use of the 4 medium sized cars, we can cover the 4 parking spaces designed on a more complex surface (Figure 2).

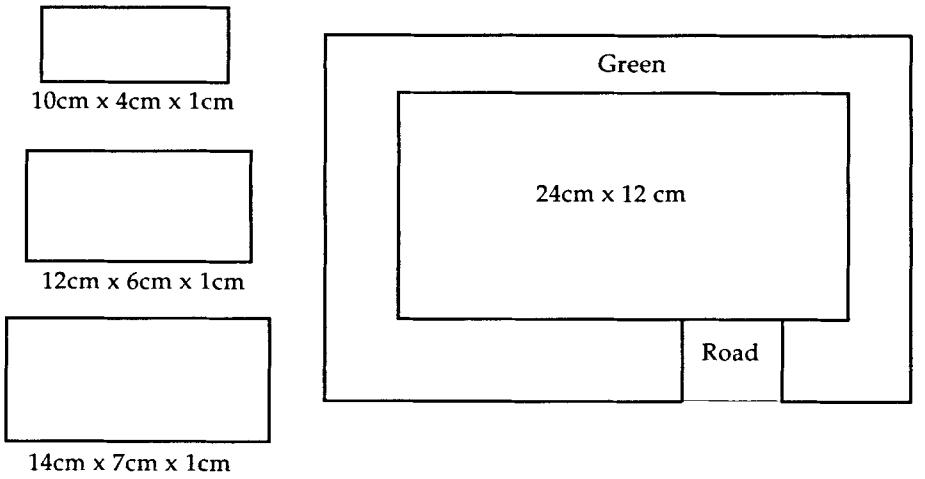

FIGURE 2

The process

The research was carried out in special schoolrooms, where children were interviewed individually. A researcher on the basis of natural observation and the analysis of the tapes recorded the efforts of the subjects. Moreover, during the experiment, a protocol of non verbal attitudes is filled in, in which the duration of the occupation with the task is recorded. The process was interrupted when the children carry out successfully the experimental procedure, or when, after failing, they stop working.

With the children of the experimental group we used material that was socially significant. We gave every subject the parking surface (Figure 2) and the 12 small cars, and after they were acquainted with the material, we analysed to them the task they had to carry out. We explained, that is, that they had to cover all of the parking space with some of the cars and at the same time, make sure that they keep the social rules: we don't park on the road and we are careful not to run over the lawn, which is beyond the parking limits, so as not to ruin it.

With the children of the control group we used material that is neutral, as far as it concerns its social importance. We gave each subject the rectangular surface (Figure 1) and the 12 rectangular parallelepipeds. After they were acquainted with the material, we explained to them what we wanted them to do. We asked them, that is, to choose some of the rectangles and place them on the surface, in a way that it would be fully covered without exceeding its limits.

After the presentation of the task the children would begin their effort. During this the researcher observed the children's actions, encouraged them to continue and reminded them the rules of the task, when they placed the rectangles in a way that exceeded the predetermined limits, without them noticing it.

Results

The analysis of the results has a quantitative and qualitative character. With the quantitative analysis of the facts we gathered, we try to accomplish comparisons between the experimental and the control group. With the qualitative analysis, we compare the characteristics of the working strategies, used by the children, whether these lead to success or failure. At the same time we observe the progress of the children according to their age. The following table presents the frequencies of the successful or unsuccessful efforts made by the subjects of the experimental and the control group.

TABLE 1: Freqencies of success an failure of the experimental and the control group

	First level of age		Second level of age		Third level of age	
	Ex. Group	C. Group	Ex. Group	C. Group	Ex. Group	C. Group
Success	5	5	13	3	23	11
Failure	12	13	9	17	5	15

As we can see, in both of the youngest children's groups, less than 3 out of 10 succeed in covering the surface, regardless of the material they use. It seems that the specific social significance we attributed to the task doesn't facilitate the solution of the problem for the children of this age. Contrary to the above the performance of the medium aged children, in both groups is different. In the experimental group approximately 6 out of 10 children deal with the problem of covering the surface with adequacy, whereas in the control group only 1-2 out of 10 subjects solve the problem. The statistically significant difference of the children's performance in the two groups, verifies our speculation about the role of the use of the socially significant material in cognitive development ($X^2=6.86$, $p<0.009$). We have similar results with the children of older ages, as, more approximately 8 out of 10 children of the experimental group solve the problem, while only 4 out of 10 of the control group do so. This difference too, is statistically significant ($X^2=7.55$, $p<0.007$).

It is particularly interesting to observe the progress of the performances in each group. As far as the experimental group is concerned, we have a significant performance increase among the subjects of the three age levels. That is witnessed by the fact, that from 3 out of 10 who succeed in solving the problem in the first level, we reach 6 out of 10 in the second and go up to 8 out of 10 in the third one. On the other hand, within the control group 3 out of 10 subjects from the first age level respond again successfully to the task, but in the second age level 1-2 out of 10 answer successfully, and in the third level 4 out of 10.

Further on, we will examine strategies the children used while they were trying to solve the problem. Let's observe carefully some aspects of the children's work. Some subjects of the first age level don't seem to understand the significance of the difference in sizes that the objects –which form the experimental material –have. This fact, leads them to a way of dealing with the task without using any distinctive strategy. Often, after they have used objects of a certain size, and haven't succeeded in covering the surface, they insist on their selection, which leads them to a final failure. Some other children of this age are strongly influenced by a topological conception of the space. They cover the surfaces, without paying attention to the instructions we gave them and

in this way the approaches they make are not accurate. Some of the younger children though, who worked with the socially significant material, make satisfactory approaches. In this case we spotted two kinds of activities. In the first one they select the right size of the objects, after a number of attempts with all the sizes, but they fail to accomplish the appropriate hand-eye coordination and so go beyond the parking surface lines on some sides and leave uncovered spaces on others (Figure 3). In the second kind of activity, they don't manage to select the right size of objects, but with a combination of other sizes they leave uncovered only a small space (Figure 4).

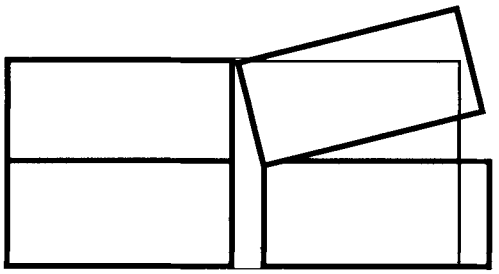

FIGURE 3

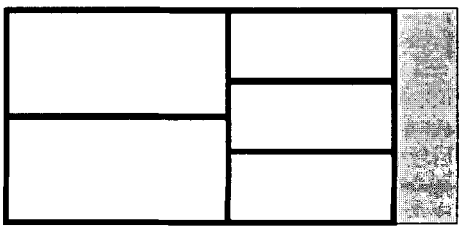

FIGURE 4

Still, there are few children from both teams who cover the surface successfully. They place correctly the four objects as shown in Figure 1, or the four cars as shown in Figure 2 and afterwards they count them. The usual strategy here, was the selection of the correct units of measurement, after trying and discovering the mistake. For example, a child experiments in the beginning, with the big size and thinks: "this doesn't fit". Then, after trying a medium sized object and realising it fits, he groups its similar shapes and places them on the surface. Another infant seems to have understood the concept of measure: after he has placed correctly the two first cars, using the one as a measure, he seeks the similar to it cars comparing them by covering the surface. Finally, some infants find immediately the unit of the right size and cover the surface.

While we were observing the strategies, which the older children used, we spotted some specific characteristics. Those characteristics become clearer, when observing the way of working of the children in the third age level. To begin with, the older children don't seem satisfied with the younger children's attempts. They try to cover the surface with accuracy and when they don't succeed in doing so, they understand they haven't responded to the task with adequacy. We also observed, that the number of children who don't use any strategies is being steadily reduced. Usually, after they have selected different sizes of objects, they experiment and in cases of failure they repeat their experimentation. Their final failure is usually due to the difficulty they face, to use as a measure the medium sized objects. Contrary to the

above, quite a few children of the second age level and more of the third one succeed when they try to work by using the unit of measurement. That means that when, after some initial trials, they choose as a unit the medium sized shape, they use it to fully cover the surface. What is particularly interesting here is that the children of the experimental group stress some points. They try to respond to the task by adopting the speculation of the capacity of the parking space, and so they formulate their assessments that the parking space admits more cars of a smaller size, or less of a bigger one.

Finally, the duration of the occupation with the task, of the children who fail, gave us one more indication of the didactic interest that the socially significant task offers. Indeed, the children of the experimental group who fail work for a mean of 5 min and 40 sec, while the corresponding children of the control group 4 min and 50 sec.

Discussion

In this research we tried to mark the significance of the development of some concepts, coming from the mathematical tradition of human thinking and psychological research, for the transition of young children's thinking from natural to mathematical sizes. Indeed, the use of measuring surfaces, by covering a selected unit during a task of social significance for the children seems to facilitate this transition.

While observing the working strategies, that children of the same ages in both groups used, we discovered that quality wise there were no differences. The nature of the tasks, which the children had to carry out was the reason for both groups, that is the one who worked with the socially significant material and the other with the neutral one, to face the same kind of obstacles. The substantial difference though, was that the socially significant material allowed to children in many more cases, the surmounting of these obstacles. Our results show that at the ages of 5-6, few children solve the problem of measuring surfaces, by covering the selected unit regardless of the kind of the material they use. The increase of children's success though, as the ages go up, gives us an indication that as children grow older, they take even more advantage of the socially significant material, in order to deal with the difficulties of their task. It seems that the social significance of the task allows quite a few children to seek for an arrangement of the cars, so as to cover the parking space. Furthermore, it appears that children get significant help by using the rules we give them, such as not being allowed to exceed the parking limits, or go on the lawn, rules which children are acquainted with in their social environment. Besides, an extra indication of the increased interest that children show for the socially significant task, is the time during which they deal with this task, even in cases of them failing. We also discovered that some children of the control group, respond successfully to their task, a fact which provides us with some indication that problems dealing with measuring surfaces, are suitable for being used as an activity object in early childhood education.

The entirety of the results in this research, verify the interest of post-piagetian assumptions, about the potentialities of quantification and measurement of physical quantities in early childhood education (Ravanis, 1998; Ravanis & Bagakis, 1998). The use of social significance as well as other techniques, like the creation of cognitive conflicts, or the use of analogical models, allows us to develop educational activities and an educational material, which contributes resolutely to the cognitive development of children. Our research activity is guided towards this direction.

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