Epistemological Understanding and Inductive Inference: A study of physics in Early Childhood Education

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Abstract

Introduction. This research addresses preschoolers' intuitive understanding of rectilinear movement and some variables which affect it, and the type of arguments used when related knowledge states are justified. A first working hypothesis is that the resolution of practical, functional situations would be based on self-regulation processes. A second working hypothesis is that feedback provided by the situations would modify their levels of epistemological understanding.

Method. The sample is composed of 40 boys and girls between the ages of 5.0 and 5.5 years, selected randomly from three private preschool educational institutions in Cali (Colombia), and subsequently assigned to two groups. The experimental material consists of four isomorphic situations based on a task by Chen and Klahr (1999).

Results. Data support the first hypothesis: the average number of actions increased significantly between sessions, strategies undertaken by the children are organized in more complex series and with greater effectiveness. Empirical support for the second hypothesis is not supported, most arguments which the children use to describe the knowledge of characters in the situation remain stable.

Discussion. A self-regulation process was identified in the children's verbalizations, which moved from mentioning actions undertaken on the material to controlling actions in advance. Positions such as that of Schauble (1996) are discussed, stating that preeschoolers are hesitant to abandon strategies despite their uselessness. The activity was ineffective in transforming the arguments they use and by implication their levels of epistemological understanding.

Keywords: Self-regulation, Epistemological Understanding, Implicit Conceptions, Physics in Early Childhood Education, Preschool, Inductive Inference.

Introduction

Research on Cognitive Development and Scientific Reasoning has inquired into the nature of intuitive conceptions that children have about certain domains of knowledge, and physics in particular (Vosniadou, 2002; Pauen, 1996). These implicit conceptions have proven to be quite solid when children are led to make causal judgments about physical facts. These causal ideas about the physical world generate predictions that continue to be consistent despite receiving contradictory information, this predictive capacity and its consistency over time are the distintive traits which they share with scientific theories in the strict sense (Pozo, Sanz & Limón, 1992).

This takes on great importance in the educational setting since these conceptions are drawn from the real world and hold a certain degree of veracity for those who maintain them, besides being generalized in an implicit manner, replacing or linking to knowledge which is imparted in educational institutions. In this way a hybrid is generated, arbitrarily and erroneously joining both types of knowledge.

A functional relationship is then created between the way we perceive the world, the generalization we give to such knowledge, and the way we perform in our world. Thus the transformation of such conceptions is a highly useful, practical objective in the educational environment; however, research in this subject has approached the problem from different positions.

One position approaches children's intuitive knowledge about physics from scientific reasoning (Penner & Klahr, 1996; Schauble, 1996), showing the solidity of certain intuitive conceptions and their significant relationship to cognitive development.

A second position, based on the need to produce learning methods for education in the sciences, seeks to modify implicit conceptions through problem-solving situations and contexts of scientific investigation. Considered to be valid strategies for using with adolescents, they should be used for drawing students' conceptions closer to those accepted by socially valid scientific knowledge (Chen & Klahr, 1999; Niaz, 1995; Pozo, 1993).

These positions vary in the importance assigned to formal instruction and to knowledge prior to completing the activity, but they agree in that in the classroom we should promote domain-specific knowledge and the scientific method (having a non-specific view of "scientific method", considering that the proliferation of different methods is an opportunity for the advance of science.)

It is then sustained that learning in the sciences should go beyond memorizing facts and formulas, less scientific content and more research processes, synthesizing of new information, and elaboration of hypotheses. It is then evident that these conceptions, though existing from an early age, are approached from a pedagogical perspective in adolescence, thus overlooking the childhood population which is generally reserved for studies of a representational nature.

This article presents a strategy for transforming younger children's knowledge about physics based on presenting problem-solving situations that differ in content, but contain the same logical structure (isomorphic situations). The consistency of childhood knowledge is closely related to the epistemological status of intuitive knowledge (see Oliva, 1999) and the conceptualization attained about such actions.

We then discover that the ability to have conscious control over strategies used in a problem-solving situation, and the way children relate to their own knowledge as a function of arguments used, are variables that become significant. There exist several concepts in cognitive psychology and particularly in scientific reasoning that are useful for analyzing such variables --self-regulation based on metacognitive processes and epistemological understanding. These allow for deeper analyses of the child's activity.

Self-regulation and Epistemological Understanding

Self-regulation activities can be considered goal-oriented strategies that allow the child to select information, putting himself at different levels of abstraction, and involving an ability to control his own activity (Lacasa, Martín, & Herranz, 1995). Self-regulation can then be considered an operationalization of metacognition, since this is characterized by reflecting on, monitoring and regulating processes of a first order (Kuhn, 2002).

It is then proposed that action upon the material produces different levels of abstraction in children as they draw out information that goes beyond the information given; this is an ability arising from a cognitive process which has been studied widely in recent years, that is, inference. We specifically propose inductive, functional inference in this study, since it is linked to direct manipulation of mechanisms, and significant problem-solving information arises, to the extent that the elements' function is understood (Ordóñez, 2000).

The inductive emerges from the identification of regularity in a pattern of data or set of evidence, and then shaping it into a hypothesis or rule which explains variation in such data (Florian, 1994). Children's performance in situations involving inductive inference has been characterized from several perspectives, and it has been said that inductive inference is probably the only process that generates really new knowledge (Johnson-Laird, 1994).

Studies about inductive inference cover the prediction of movement vectors generated by at least two forces (Pauen, 1996), the causal explanations of animate and inanimate movement (Gelman & Gottfried, 1996), and generalization of knowledge of non-visible properties in exploratory play (Baldwin, Markman, & Melartin, 1993). These studies have shown children's growing ability to generate knowledge through experimentation which is inherent in problem-solving situations.

Nonetheless, although children's performance improves with relation to the activity performed and to abilities gained from cognitive development, the arguments children use about knowledge show a peculiar relationship with the characteristics of the situations they are solving. Flavell, Mumme, Green and Flavell (1992) put forward that children create a transformation on *their own* knowledge inasmuch as they manage to differentiate it from outside knowledge.

These arguments reveal how children find the difference between their own thought and outside thought, and their different knowledge states (Kuhn, Cheney & Weinstock, 2000a), simultaneously analyzing their validity (Pillow, Hill, Boyce & Stein, 2000). This ability to think about knowledge and how it is acquired is what Hofer and Pintrich (1997) call epistemological theories, taking on relevance since they include children's argumentation about different knowledge states.

These theories are what has been called epistemological understanding, the ability to coordinate subjective and objective dimensions of knowledge (Kuhn et al., 2000a). It is said that knowledge is in the objective dimension inasmuch as the cognoscent subject considers specific knowledge about a certain topic to be an entity found in the real world and therefore knowable with certainty, independent of the observer who accesses such knowledge.

A subjective dimension of knowledge is that where weighing the knowledge's validity goes beyond an object cogniscible to a cognoscent subject. This generates an awareness of the knowledge's uncertainty, having originated in human minds. This step has positive consequences for education since it introduces the ability to compare diverging opinions about the same matter, opening the door to critical thought about different arguments.

Coordination of dimensions confirms the objective aspect of knowledge and recognizes the uncertainty brought about by the human mind. Thus, two opinions may be legitimate and valid but one of the two must be more so, according to evidence that supports one argument or another. Coordination between dimensions is reached when one recognizes that reality is not directly cogniscible, but can be evaluated according to criteria of arguments and evidence. This is where evaluation of evidence becomes an essential process.

This conceptualization about the subject–object–knowledge relationship is found in processes which underlie the child's creation of a world where the origin determines whether given knowledge is relevant. As cognitive development takes effect, knowledge becomes an object of evaluation through the process that shapes it and through the evidence that sustains it.

This is where the knowing subject has a creative, active role, *injecting meaning and validity* into perceived reality, both in himself and in others. This conceptualization about the world gives rise to the idea that epistemological conceptualizations will always depend on metacognitive processes that a knowing subject possesses at a given moment. Kuhn and Pearsall (2000) have tried to show that the person's epistemological level, along with the inherent demands of each experimental situation, exercises an influence on the way we use our intellectual skills, and even influences acquisition of new knowledge.

I therefore propose that the resolution of practical, functional situations would be based on processes of self-regulation, since actions stem from a largely implicit knowledge, though susceptible to the impact they have upon the material. Hence they become explicit to the extent that they interact with the situation. This is a first working hypothesis.

Epistemological understanding is closely related to how persons are able to distance themselves from their own knowledge and evaluate a given phenomenon from the perspective of someone else. Feedback provided by such situations would modify their arguments as it allows them to evaluate others' beliefs. This is a second working hypothesis; analyzing the correlation that exists between self-regulation and epistemological understanding is left for the future.

In order to address these hypotheses, we set a general objective of determining transformations in implicit conceptions about physics in children between 5.0 and 5.5 years of age, as they solve isomorphic problems of an inferential, inductive nature. From the various levels which the situation entails, integrating actions for problem-solving and verbalizations for evaluating a knowledge state, two specific objectives are derived:

a) Analyze children's ability to solve problem situations and evaluate the evidence that these situations provide, their strategies being an index of self-regulation, and
b) Examine levels of epistemological understanding in arguments used for describing the knowledge state of the characters in the situation.

Method

Subjects

The population comprises 120 boys and girls from three private preschool institutions, belonging to socioeconomic stratum 6 in the city of Santiago de Cali, this being the highest stratum in a classification made by the city's Public Services. The final sample comprises 40 boys and girls between the ages of 5.0 and 5.5 years, having been selected randomly through a computer program (SPSS). Only those children whose parents gave written authorization participated.

Experimental Situations and Material

The experimental material is based on a situation from Chen and Klahr (1999). It consists of two movable ramps that produce four different degrees of inclination (15^o, 30^o, 45^o, 60^o). One third of the surface of one ramp is covered by a non-translucent plastic; the hidden surface has speed reducers, causing a greater acceleration to produce jumps along the way, and so delaying arrival. Only a person who produces a constant acceleration from the beginning of the one ramp will be able to solve the situation.

The situations are related to empirical verification of beliefs offered by two characters who are like F1 automobile mechanics. The action performed on the material generates evidence reporting to the veracity of the characters' propositions of a mechanical nature. This is where self-regulation comes in: the veracity is based on empirical verification performed by the child when solving the situation. These beliefs are a control measure since they restrict formulation of a hypothesis that would arise if the phenomenon which causes the vehicles' functioning were sought for.

One main situation and three isomorphic situations were presented; the latter used the same material but with different settings. The assumption is that since they contain a common structure, they would require the problem-solvers to create and use inductive, functional inferences. This way we can evaluate the understanding reached for each situation by controlling traces of learning brought about by the first resolution.

The specific domain to which this situation belongs is the physical, understood as a set of representations that a given knowledge sustains (Karmiloff-Smith, 1992). An early basic understanding of dynamic properties exists and does not require the subject's insertion in a formal and/or advanced school setting. The thrust-velocity relationship approached in the experimental situation is verified in a familiarization situation.

Experimental Design and Plan

The design included an experimental group and a control group (named groups 1 and 2 respectively). The independent variable is the number of situations, four for the experimental group and two for the control group. The situations were presented in a corresponding number of sessions with an hour-long interval between sessions; age of participants was also controlled. The instructions for the situation were: “Something happened, the cars should have arrived at the same time. The first mechanic *thinks* it is a problem with the track and he wants to change it. A second mechanic *thinks* it is a problem with the start-up, and he wants to push it harder, could this be right? You must help them know whether it is right or not”.

Immediately afterward, the child performed the activity by modifying characteristics of the tracks at will. Then he was asked the control question in order to determine comprehension of the task: “Do you remember what this mechanic thought? Was he right or not?” The data presented here includes only those subjects who responded affirmatively and correctly to the first question.

Subjects were divided into two groups; the four situations were presented to the first group and only two to the second group, considered the control group. Comparisons between the two groups create a possibility of identifying and measuring variations due to learning.

Categories of analysis

Analysis categories for the problem-solving activity are related to the ability to generate and work with information that arises from interacting with the experimental material (Ordóñez, 2000) and they establish a hierarchy with respect to self-regulation attained over the course of the sessions:

Category A: Establishing relationships between constituting elements. This criterion refers to relationships of a physical type that are established when taking action upon the elements of the experimental material, called constituting elements. Establishing these relationships entails identifying directly proportional relationships between physical variables, for example: lesser angle means lesser velocity, greater force means greater velocity. Initially this implies an exploratory, inductive activity upon the material, but later anticipation necessarily limits the type of actions on the ramps, once it is understood that a certain type of action generates specific results.

Category B: Use of relevant information. This category recognizes the ability to get the cars to achieve desired performance on the ramp that has speed reducers, by manipulating elements present in the situation. It implies an ability that refers to inductive, functional inferences, but precedes the belief-evidence relationship.

Category C: Evaluation of evidence. This is a higher-level category and contains the previous ones. It is considered sufficient indication of the ability to evaluate actions and their impact if the child: (1) first observes differences between the two cars' behavior, (2) afterward manages to get the results required by the situation, and (3) accurately evaluates the veracity of possible answers to the original problem (the mechanics' beliefs), selecting the correct answer.

The classification of epistemological understanding is based on proposals from Hofer and Pintrich (1997), and arises from the children's justifications and arguments about the mechanics' beliefs, generating three levels: a) At the absolute level, subjects recognize, based on their prior knowledge, that it is possible for a false belief about a certain event to be formed in someone's mind, b) At the multiple level, reality is not directly cognoscible, rather the beliefs and knowledge of human minds intervene, making the resulting knowledge uncertain and c) At the evaluative level, one recognizes that reality is not directly cognoscible but can be evaluated according to criteria of arguments and evidence.

Results

Only data from sessions 1 and 4 are presented, shown as a function of the two proposed hypotheses. For the former, we present the average of successful actions per category, namely, those that produce suitable results for solving the task; these are considered an index of self-regulation. Concerning the second hypothesis, the data are presented based on levels of epistemological understanding. After checking homocedasticity, we approached the normal variable, and a X^2 Chi square was performed using the Yates correction for continuity.

Table 1. Average number of successful actions by category and group

	Type of Actions upon the Material					
	A		B		C	
Session	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
1	11.5	13.7	10.4	11.1	2.4	1.8
4	20.8	15.4	24.6	14.7	8.1	3.7

Table 1 presents the average of successful actions in task resolution by sessions. For the control group, there were only sessions as a function of the independent variable. The average increased significantly between sessions for the experimental group (X^2 *=4.01*, d.f.: 1, p< 0.05 for category A, X^2 *=4.27*, d.f.: 1, p< 0.05 for category B, and X^2 *=3.98*, d.f.: 1, p= 0.05 for category C); for the control group there is a tendency to rise, though it does not become significant in any category.

Statistically significant differences between both groups were not found with X^2 in the first session (X^2 *=2.90* and X^2 *=2.78*). In order to determine the significance of differences between the two groups in the final sessions, we used the Mann-Whitney test for both groups with independent data. We found them to be significantly greater than expected, due to chance with a risk of 5% in all three categories, particularly in category C (*U*= [1550.5; 130.5], p<.05) where there is a clearer possibility of the children evaluating available evidence.

Table 2. Epistemological level over the course of the sessions (group 1 only)

Percentage of participants showing a predominantly absolute level			
Session 1	Session 2	Session 3	Session 4
90%	85%	90%	80%
Percentage of participants showing a predominantly evaluative level			
Session 1	Session 2	Session 3	Session 4
10%	15%	5%	20%

Table 2 presents the percentage of subjects corresponding to the respective levels of epistemological understanding; expressions indicating the presence of a multiple level were not found. Results show that over the length of the different sessions justifications of an absolute nature proved stable in the type of arguments used for describing the mechanics' knowledge of the situation; however, justifications of an evaluative nature did undergo fluctuations.

Discussion

As a function of results obtained and hypotheses proposed, two themes can be discussed: a) the relationship between implicit conceptions and resolution of isomorphic problems of an inferential, functional nature, and b) children's arguments about the mechanics' knowledge and its veracity, these being indicators of their levels of epistemological understanding.

Data support the first hypothesis. In the repeated resolution of practical, functional situations, actions which the children undertake in solution-seeking are organized in more complex series and with greater effectiveness. Relationships between the mechanics' verbalizations and the effectiveness of their own action sequences are made explicit for the children, thus adding metacognitive characteristics.

In this way self-regulation processes identified were based on a change in the children's verbalizations, moving from mentioning actions undertaken on the material, to controlling those actions, by means of establishing relationships between the actions to be undertaken and those previously performed, and their respective effectiveness. As Lacasa et al. (1995) propose, children situate themselves in different levels of abstraction in order to control their own activity; in this sense the incorporation of planning becomes a resource of metacognitive nature.

Recently, Kuhn (2001) has approached the study of metacognitive processes by proposing a distinction between metacognitive knowing and metastrategic knowing: the distinctive characteristic of the former is in its being a declarative knowledge, while the second is based on knowledge of the task and the effectiveness of available strategies for reaching the solution.

From this classification, one finds interesting links in self-regulation as developed over the length of the sessions, since during the sessions a declarative knowledge is formed which gradually gives meaning to the action performed. From a perspective based on cognitive processes, as the number of sessions increased, the action which was an index of inductive inference become indisputable. During the activity relationships appeared in the material which for the children were not evident at the beginning; thus they surpassed the given information and drew out new knowledge, this being the defining attribute of inference.

But is only a successful resolution what authorizes speaking of inference? The relationship to self-regulation which we discuss in this article leads one to think that only when the subject can use the information given from the situational elements, and discovers something new in an explicit manner, only then can one speak of a resolution through inductive inferences, in this case the indicator being identification of the physical relationship proposed in the task.

Thornton (1998) proposes that children from a very early age show behaviors to which one can attribute an inferential component, allowing them to depend on their own reasoning and not on the task characteristics. In this way children move to being guided by the information that they elaborate and not by the perceptual elements of the task.

Through the children's activity we get a view of the strength and characteristics of physical conceptions they elaborate. In the initial session, and recurringly (61.5% of typical actions from both groups), it was considered that thrust and its resulting velocity was the unique, sufficient requirement for solving the problem, this being the first implicit conception found in the physical plane. The act of quickly running over the speed reducers caused jumps which decreased velocity, only those who inferred a gradual acceleration were able to successfully resolve the task.

Schauble (1996) analyzes the behavior and beliefs of preschoolers with regard to the physical domain and in particular hydrodynamics, finding preschoolers to be reluctant to abandon invalid strategies or conceptions, despite experience proving their uselessness; in addition their conceptions are transformed during sessions to a greater proportion than in adults.

This study, on the other hand, found that children gradually inferred that acceleration was relevant in order to overcome the speed reducers on the ramp (from 22.5% of attempts in the first session, to 42.8% in the second). Probably mechanics and rectilinear movement are more transparent than hydrodynamics since they are more noticeable in the practical world. These results illustrate children's capacity to evaluate evidence.

Results openly contradict proposals such as those by Kuhn, Amsel and O'Loughlin (1988) when they affirm that small children use evidence in favor of their own theories or they use evidence in order to construct new theories, but they fail to understand how these new theories differ from the first. When faced with this situation children were effective in transforming their conceptions by evaluating evidence.

However, it is interesting to analyze what statute we might assign to physical beliefs as presented by the subjects: can they be considered theories as several authors claim? (Vosniadou, 2002; Pozo et al., 1992). Firstly, one must take into account that when speaking of theory, there is no claim that it be so in an explicit sense. Gopnik and Wellman (2002) propose that at five years of age one possesses general constructs that are explanatory, predictive and are based on beliefs and not desires, the latter being characteristic of younger ages.

Two results allow us to give a certain theoretical status to the participants' ideas; velocity turned out to be a unique variable in rectilinear movement, which was sufficient for performing projections on movement of the vehicle and how far it could reach up the ramp. However, it was sensitive to change, the content of arguments allowed us to see that it is beliefs about knowledge that explain the activity.

In contrast to the large changes observed in the inferential, self-regulating activity, no large change was found in arguments used and their levels of epistemological understanding. Therefore, empirical support for the second hypothesis was not found, the majority of children are located at an absolute level. Kuhn and Pearsall (2000) propose that the beginnings of metacognitive abilities with relation to coordinating knowledge dimensions should be looked for in the Theory of Mind, since it is necessary to understand that another person can have diverse beliefs about an event and that these may differ from one's own.

Even though the participants' age makes one think that a mentalistic theory is already present, the children had difficulty relating information provided by the situation to the mechanics' original beliefs; this result reinforces earlier research. A study by Kuhn et al. (2000) inquires into the importance of type of knowledge domain and its relation to cognitive development in epistemological judgments; they found 75% of fifth-grade children to be placed at the absolute level.

Repeated resolution of isomorphic problems was not effective in transforming their arguments and the relationship of these arguments to information found in solving the task. In this case, and as an explanatory hypothesis, restrictions of a cognitive nature prevailed and prevented a distancing between the mechanics' and the children's beliefs. A future correlational analysis between the problem-solving activity and the children's arguments is needed.

It has been maintained that appropriate instruction is indispensable in order for elementary schoolchildren to learn and transfer basic strategies when evaluating experimental designs (Chen & Klahr, 1999); we also recognize that the long-term relationship between methodology and comprehension is not explored here. Nonetheless, this study shows that a situation where inductive analysis is performed through resolution of isomorphic situations significantly improves physical intuition of preschoolers and further enriches the delightful experience of early childhood education.

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