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SOCIAL AND DEVELOPMENTAL ASPECTS OF IMPLICIT LEARNING

by

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Abstract

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Implicit learning is the automatic and nonconscious acquisition of knowledge of the underlying rule structure of a complex stimulus display. According to present theory (Reber, 1992; Roter, 1985), implicit learning should occur with relative independence from age or developmental effects. Thus children should display an ability to learn implicitly similar to that of adults. Few studies have assessed implicit learning in children; no study has assessed the effect of social interaction on implicit learning. The present study evaluates the ability of children from 5-10 years to demonstrate implicit learning of one and two dimensional artificial grammars, alone or in interaction with a peer. One dimensional artificial grammars vary one salient attribute to determine elements of the grammar (i.e shape or color). Two dimensional artificial grammars vary two salient attributes (i.e. shape AND color) to determine its elements.

Eighty-seven children between 5-10 years were given a pretest to determine their ability to coordinate two stimulus dimensions through conscious, explicit processes. One- and two-dimensional implicit learning was evaluated in each child either working alone or with a peer matched for age, ethnicity and gender. Results suggest that there are differences in implicit learning of one and two dimensional artificial grammars. Children between 5-10 years did not learn two dimensional grammars through implicit processes, as expected given present theory. Social interaction produced no differences in implicit learning; however there was an increase in ability to explain what was learned implicitly. The study explores the implications for further research in implicit learning.

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INTRODUCTION

Can one acquire knowledge of a rule-based system without conscious awareness? Can acquisition be affected by the surface structure of knowledge or by the circumstances surrounding acquisition? This study is an examination of **implicit learning**, the automatic and nonconscious acquisition of knowledge of the underlying rule structure of a complex stimulus display. It is an attempt to expand the experimental study of implicit learning past its roots in a strongly cognitive, non-developmental tradition into social and developmental domains. It is my belief that if this is accomplished, we will increase the explanatory power of the concept of implicit learning.

Implicit learning is often defined as a mental process which may underlie the acquisition of complex rule systems such as those used in language (Reber, 1989) and in social interaction (Lewicki, 1986; Lewicki and Hill, 1987). Implicit learning-like processes are posited in such diverse areas as economics (Nelson and Winter, 1982), scientific research (Polanyi, 1962), and knowledge of the physical world (Chi & Slotta, 1993). However, implicit learning theories themselves do not incorporate developmental or social factors as explanatory or descriptive variables.

In this context, social factors mean the effects of other persons on learning in the individual. These factors could be manifested as global, distal, cultural influences on implicit learning (do individuals from different cultures implicitly learn in different ways?) or as more proximal, contextual influences on implicit learning (do interactions with other persons have an effect on implicit learning?). In other areas of psychology, the effects of other persons on the individual have been well documented. Zajonc's (1965) work on social facilitation, the improvement of individual performance in the presence of others, and Asch's (1958) work on conformity of individual's judgment in the face of group pressure are two examples from the social psychological literature. The work of Doise and Mugny (1984) on the effect of peer interaction on cognitive ability in individuals is an example from developmental psychology, to which this paper will return in greater depth.

In this context, developmental factors question whether there are mechanisms of development that result in qualitative or quantitative change in the process or manifestation of implicit learning. Qualitative change in implicit learning could manifest as a change in ability to learn different kinds of information (e.g. first social interaction rules and then language rules), or to implicitly learn in a different fashion. Quantitative change in implicit learning could manifest as a change in the amount of information learned through implicit means. Social and developmental factors must be examined in implicit learning research if the concept will fulfill its early promise as an explanatory variable within the diverse areas noted above.

This dissertation has been designed to serve multiple purposes. One purpose is to examine the effects that peer social interaction factors have on implicit learning. Can peers working together in a dyad affect their (implicit) learning of a set of rules governing the serial order of colored symbols? Another purpose is to examine the relationship among developmental level, stimulus dimensions and demonstration of implicit learning. Do children of different ages differ in their ability to implicitly learn? Do symbols of different surface characteristics affect the ability to learn these rules? The present study examines a different methodology (one and two dimensional artificial grammars), and to assess whether using both one and two dimensional artificial grammars adds to the study of conscious and nonconscious processes.

In considering implicit learning as a research paradigm in the area of cognitive processing, it can be positioned as the search for universal attributes underlying all knowledge acquisition. This may lead one to conclude that implicit learning is a basic, non-developmental process of mind distinct from, and unaffected by, social and cultural factors. This conclusion is examined in this present study because existing methods of assessing have ignored qualitative and quantitative change in the individual. Those few studies which do examine age differences in ability to implicitly learn use a method that may guarantee no differences in learning across age.

This study investigates qualitative change in implicit learning across developmental "level." It will consider whether implicit learning can be affected by the social environment in which learning takes place. It will also investigate whether the physical instantiation of the stimulus material to be learned can help to demonstrate that developmental and social factors affect implicit learning.

As this discussion unfolds, the question of what consciousness is, or what it means to be conscious is not considered. For the purposes of this paper, let us say that consciousness is the phenomenological awareness of some "thing," that thing being the physical surroundings or a rule, or a sensation of being in pain. You, the reader, know that you have read "read" twice, or will become aware of that fact now. This phenomenological awareness is consciousness.

Social Perspectives

In psychology, many theoretical and methodological traditions are invoked to explain the acquisition of knowledge. One possible taxonomy of traditions places social and cognitive explorations as the end points of a continuum concerned with social versus individual psychological explanations. In contemporary social-psychological literature, there is a stronger emphasis on mechanisms of acquisition mediated by social and cultural forces than on mechanisms of acquisition within the individual. This perspective is in the tradition of theorists like Kurt Lewin (1951), and some aspects of Piaget's theory (Piaget, 1932/1965; Bearison, 1991; Chapman, 1986). In the social-psychological tradition, the individual is a black box. In physics, a black box is an entity which produces output and accepts input; its inner work is an unknown and sometimes unknowable process or mechanism. Similarly, in strong examples of the social-psychological perspective, the individual is seen as an entity which receives information from collective societal forces and acts upon this information. Intraindividual processes do not play a large role in understanding the acquisition of knowledge. The individual acquires information about the social world, and is an active agent within that world. But the forces which drive the individual to be active in the social world are forces outside of the individual. The individual *qua* individual is not analyzed; processes and structures in the individual are secondary in social psychological analyses. The individual as a social agent, and the qualities of the individual which influence the individual as a social agent are analyzed; the individual qua individual is relatively passive in social psychology.

An example of the tendency to "black-box" intraindividual processes is the concept of internalization. Lawrence and Valsiner (1993) examine the use of the theoretical construct of internalization with social-psychological theories of cognition. They conclude that a major weakness of such theories is the reliance on internalization as the mechanism of transferral of interindividual products to the individual. It is not the use of internalization *per se* that causes such weakness; it is the lack of theoretical and empirical work on the process of internalization that leaves well articulated social-psychological theories of cognition unfinished.

Social-psychological research tends to be domain specific and contextually bounded. In social-psychological studies, one sees discussion of such areas as friendship dyads (Berndt, 1989; Furman, 1989), situated learning (Lave, 1988) and education (Ogbu, 1978). These discussions are contextually bounded by definition: the focus is on the relation of the individual within a society and within a cultural context. For example, Ogbu (1978), in his discussion of differential performance of African Americans in school, focused on the effects of belonging to an involuntary immigrant group on the individual, and the treatment of voluntary and involuntary immigrant groups in educational settings. The individual is acted upon in Obgu's analysis by the social effects of membership in a group, and this membership determines action and reaction in the individual. For many social-psychological studies, the metaphor of choice is a sociocultural web. An individual is seen as an elementary, indivisible unit suspended in a network of social relations, acting and being acted upon by social forces. It is the nature of this web, and activity within this web, that are the foci of social-psychological research.

The level of analysis at which social-psychological perspectives are based is that of social interaction. The differences between researchers within this perspective are based not only on their differing approaches to explaining social interaction, but on the relative importance placed on explanations which make connections with other levels of analysis, particularly at the level of the psychology of the individual.

Cognitive Perspectives

The other end point of the individual/social continuum is the cognitive-psychological perspective. This perspective is an individualistic one, a search for the universal qualities of knowledge acquisition **within** the individual. The noise of individual differences (individual, developmental, or contextual) is screened in the interest of understanding the true universal nature of human and non-human information processing. Once the noise of individual differences is muted, then the remaining data will explain the nature of individual information processing shared by all. The specific meaning of information is relatively unimportant in this perspective, e.g. the processing of English words is similar to that of Finnish words because they are both natural languages, and the mechanisms for processing natural language are the same for all natural languages.

Critiques of psychology in general (Gergen, 1982; Reid, 1993), and cognitive psychology in particular (Sampson, 1981) address subjectivist and individualistic reductions within psychological theory. Within cognitive psychology, the subjectivist reduction is played out as the primacy of mental structures and processes of the knowing subject. Cognitive research centers on the subjective experience of the research subject, as the subject internalizes, transforms, and represents the objective properties of "outside" reality. The individualistic reduction grants primacy to structures and processes of the individual, divorced of connections to other people. Within the grip of these two reductions, the unit of analysis becomes the isolated, individual mind. This individual mind actively processes outside reality, which remains passive. Passive here reflects the belief that the outside world and its objects are constituted by the experience of the individual; transformations occur in the individual's mental structures and processes rather than in the object. The social and historical constitution of reality is ignored (Sampson, 1981).

While some may not subscribe to such an extreme view of cognitive psychology, the effects of subjectivist and individualistic reduction, as well as the search for universal qualities within the individual lead to decontextualization in analysis of mental life in cognitive research. In addition the universal qualities that are examined are typically that of the adult form of acquisition. The knowledge acquisition system is understood through the analysis of the structural and functional qualities of the system. Within this perspective are found theorists such as Fodor (1983), Anderson (1983), Holyoak and Nisbett (Holland, Holyoak, Nisbett, & Thagard, 1986). Developmental theorists who fall loosely into this area are Keil (1992), Carey (1988), and Piaget (1950; 1975/1985).

Comparison of Social and Cognitive Psychological Perspectives

Obviously, the social and the cognitive perspectives are not mutually exclusive in the practical application of theory and methodology. These two approaches may appear to be dichotomous, especially for extreme examples of each. Some theorists discussed above would probably feel comfortable with expressing the differences between the two on a continuum. For example, Piaget's (1971) main emphasis seems to be on the cognitive development of the isolated individual; at the very least he acknowledged the importance of sociocultural forces on the development of the individual (Bearison, 1991). The differences between the two perspectives is also muted in developmental psychological research, which tends to pay more theoretical attention to both inter- and intrapsychic sociocultural forces. The danger of dichotomizing intra- and interindividual approaches in psychology has been expressed in poststructuralist critiques of psychology (Sampson, 1981). The appropriateness of demarking perspectives lies in parsing of the givens of differing perspectives and in making these givens explicit. Dichotomizing approaches leads to a stereotypical understanding of theory serving neither theory nor reader of theory (Bearison, 1991).

For the social-psychological perspective, context and its effects are paramount; for the cognitive-psychological, context is relatively unimportant. For the cognitive-psychological perspective, the internal function of the individual is the unit of analysis, for the social-psychological, the unit of analysis is found between individuals. These differences are born of differing theoretical positions; these positions delimit the choice of domain and method of study within social and cognitive psychology.

At the heart of all research, there exists theory which determines the questions, acceptable answers, and techniques for deriving answers from data (Kuhn, 1970; Lakatos, 1978). At times the concepts and givens which drive a theory are explicitly stated. In other cases, these core concepts and givens are held so firmly by members of a discipline that they are neither questioned nor explicitly stated. It is often forgotten that these core concepts and givens are theoretical positions and they assume the force of natural law. This over determination exists, albeit to a lesser degree, in current explorations within cognitive- and social-psychological perspectives.

Both perspectives have assumptions and expectations which preclude a complete understanding of the process of acquisition of knowledge. The social-psychological perspective, through its focus on the individual as an elementary unit of analysis, provides a weak analysis of the experience of the individual. In extreme cases, the individual is treated as an unknown and unknowable entity. The cognitive-psychological approach, through its emphasis on information processing, misses the importance of information itself, its meaning, and its implications for processing because of its nature.

The importance of the meaning of information, as opposed to structure and function, will be explored further in my discussion concerning implicit learning.

Synthesis of Social and Cognitive Perspectives

Given the differences cited above, and the deficiencies of extreme examples of each perspective, it may be useful to consider a synthetic approach. Such a synthesis may utilize both social-psychological and cognitive-psychological analyses of the individual and society. It could provide a more complete understanding of learning, in particular, and cognition in general. In addition, insights impossible without analysis from a dualistic/synthetic perspective become clear by elimination of the acontextuality of the cognitive-psychological approach as well as an appreciation of the commonalities of different kinds of knowledge and their acquisition. I would like to refer to the perspective taken by such approaches as the sociocognitive perspective (Luria, 1976; Resnick, 1993).

The sociocognitive perspective would combine the analysis of the sociocultural web, and the individual's place within it, as well as the integration of the individual *qua* individual within this web. The combination of information processing techniques, with a focus on the sociocultural environment in social-psychological approaches allow for a more complete understanding of knowledge acquisition in the individual in society. In contrast to the individualistic and subjectivist reduction of the cognitive-psychological approach, the individual is (re)connected with structures and processes of other people.

The subjective experience of the research subject is still important, but there is a co-creation of subjective experience from the subject and from outside reality. For example, Luria (1976) in his examination of cognition in the peasants of Soviet Central Asia, analyzes the effects of interpsychic cultural forces upon the cognitive activity of individuals. For Luria, mental processes and human action change the environment which then in turn changes mental processes. Finally, the social and historical constitution of reality and the implications social and historical forces have upon the construction of reality cannot be ignored.

This sociocognitive synthesis is truly a novel approach, not an additive one because of the transformation of the core concepts of each of the theses involved in its constitution. The universality of qualities searched for in cognitive-psychological research is transformed into study of the differences and noise as well as the commonalities of cognition. The individualistic and subjective reductions of cognitive psychology are expanded into the contextualized individual and the co-creation of subjective reality. Processes in the individual are given equal theoretical weight compared to interindividual processes in the sociocultural web.

Piaget, who stressed in his work the nature of cognitive development in the individual, nevertheless paid strict theoretical attention to social factors involved in cognitive development (Chapman, 1988; Bearison, 1991). Those who have worked within his theoretical framework have extended the paradigm more explicitly into an understanding of social factors of cognitive development (Ames & Murray, 1982; Bearison, Magzamen, & Filardo, 1986). Piaget himself in his sociological writings

(Piaget, 1932/1965), as well as in his writing on intelligence (Piaget, 1950) acknowledged the necessity of accounting for social factors.

Literature Review

The literature review will place implicit learning research within a class of cognitive psychological investigations into the cognitive unconscious, After a deeper examination of implicit learning research, a program for assessing ontogenetic development of implicit learning is suggested; this program informs the empirical portions of this dissertation.

The Cognitive Unconscious - A Cognitive-Psychological Perspective

Kihlstrom (1987) defines the cognitive unconscious as "mental structures and processes that, operating outside of phenomenological awareness, nevertheless influence conscious experience, thought, and action" (p. 1445). Depending on one's perspective and training, the conscious "horizon" defined by this definition can be close or far away. A clear delineation of conscious and unconscious in such a malleable conceptual space is essential to comprehend and assess the many contributions to our understanding of the cognitive unconscious. The cognitive unconscious is so named because research on the cognitive unconscious is conducted within a cognitive psychological paradigm. The designation also differentiates this approach from other perspectives, such as the psychoanalytic or psychodynamic paradigms.

Greenwald (1992) distinguishes among levels of analysis in his discussion of the work on the cognitive unconscious. The levels are based upon the stimulus materials used in research in this area as well as the relative depth of the unconscious response required of the participant. He suggests that, in order from lowest (most elementary) to highest, these levels are: **unconscious cognitive activation, unconscious establishment of memory, and unconscious cognitive analysis.**

Unconscious Cognitive Activation

The first level of analysis, unconscious cognitive activation, is characterized by the activation of the brain by the input of stimuli, without higher order processing. The important aspect of stimuli at this level are their physical characteristics. For example, these may be the volume and frequency of a tone in a dichotic listening study or the shape and color of a Chinese pictograph in a dichotic viewing study.

Examples of research dealing with unconscious cognitive activation are found in experiments on selective attention. Selective attention studies such as dichotic listening demonstrate the unconscious analysis of information in secondary attentional channels. Participants are required to pay attention to information coming from one source (primary attentional channel) while consciously ignoring information from a secondary attentional channel. Participants are merely required to show recognition of information from the secondary channel, through either a shift in voluntary attention, or memory for this information. This recognition indicates that there has been some kind of processing of information from secondary channels, whether that information consists of one's name (Moray, 1959) or words which were accompanied by an electric shock (Dawson and Schell, 1982).

Unconscious Establishment of Memory

The second level of analysis, unconscious establishment of memory, is characterized as memory without conscious knowledge. At this level are found experiments in implicit memory and subliminal activation. Implicit memory is defined as the memorial residue of an earlier experience in the absence of any comparable phenomenological sense of the previous experience (Reber, 1992). One area of implicit memory research in cognitive psychology has used clinical research with patients with a variety of amnesic disorders. All amnesics have anterograde amnesia, which is the inability to remember new information. An oft-told tale is that of Claparede and the Korsakoff amnesic (Schacter, 1987). Claparede's patient is unwilling to shake hands with the doctor after Claparede pricks the hand of the amnesic patient with a hatpin. After interrogation, the patient states that "Sometimes pins are hidden in people's hands." The patient did not remember the hatpin incident phenomenologically, yet the incident affected her behavior.

More systematic research on this phenomenon shows that amnesics have near normal retention of a list of words tested by fragment cues as compared to severe impairment by free recall and recognition tests (Warrington and Weiskrantz, 1968). This normal retention is dependent upon the instruction set given to the participants. If they are given implicit instructions, (i.e. complete the fragment with the first word that comes to mind), then retention approaches normal levels. If they are given explicit instructions to use fragments as clues to remember the previously studied words, the amnesics were unable to perform as well (Graf, Schacter, & Mandler, 1984). This difference in performance is mirrored in implicit learning research, and this differential performance based on task instructions will be an important part of my discussion of the relationship of the conscious and nonconscious.

In subliminal activation research, there is evidence for a subliminal mere exposure effect. A stimulus is presented under conditions that render the stimulus unrecognizable to participants. The participants are given two-choice, forced-choice tests of preference, and are found to prefer exposed stimuli to unexposed stimuli (Kunst-Wilson and Zajonc, 1980). This effect may be considered another member of a class of research in implicit memory.

Unconscious Cognitive Analysis

The final level of analysis is that of unconscious cognitive analysis. The phenomena studied at this level involve not only the retrieval of memories, but cognitive analysis of this information to grasp regularities of the retrieved memories.

This level differs from the two previous levels in the depth of cognitive processing required to be demonstrated. Cognitive activation requires demonstration of mere awareness of the stimulus, while unconscious establishment of memory requires demonstration of retention and retrieval of memory traces of the stimulus. Both levels involve understanding of previously encountered information. The level of unconscious cognitive analysis requires representation and analysis of the stimulus environment, in order to apply knowledge to new material. The major research program at the level of unconscious cognitive analysis is implicit learning.

Implicit Learning

Implicit learning is the acquisition of knowledge largely independent of awareness or conscious attempts to gain knowledge. Implicit learning is a phenomenon studied within a cognitive-psychological paradigm and as such shares many of the difficulties listed above in understanding cognition and mental life. However, it serves well as the beginning of an understanding of how an individual gains knowledge about a world which has never been explained.

Implicit learning differs from implicit memory in that implicit learning requires the analysis of the relationship between stimulus elements and the application of the results of this analysis to new stimulus materials. Implicit memory requires only the memory of stimulus elements. Both of these are considered implicit because there is no conscious, voluntary intent to learn or memorize during the presentation of stimulus materials.

Research in Implicit Learning

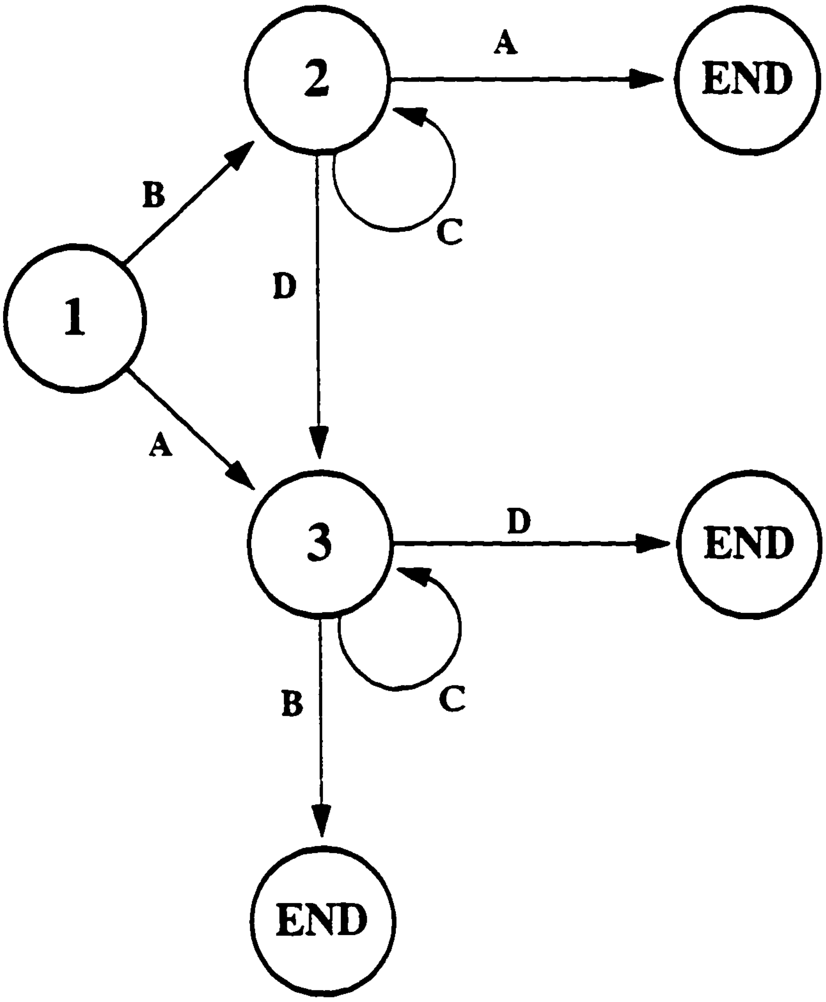
The representative experiment in the study of implicit learning is the artificial grammar paradigm designed by Reber (1967). An artificial grammar (see Figure 1) consists of a set of rules which govern the order of a set of symbols presented to participants. The set of symbols is usually based on variations of one dimension or quality. Letters, geometric shapes, colors, numbers, and animal shapes have all been used as symbols in artificial grammar implicit learning experiments. The grammar generates a finite set of strings called grammatical strings. The experimenter chooses a small subset of these grammatical strings as exemplars of the total set.

In the learning phase, the participants are presented with these exemplars, one string at a time. The participants are not informed of the rule-governed nature of these strings, but are only asked to observe, copy, or memorize them as exemplars. After presentation, the participants are told that the strings all follow a complex set of rules and can be regarded as examples of good or acceptable strings. They then participate in the testing phase, in which they are shown pairs of strings, one grammatically correct and one incorrect. In a two-choice, forced-choice format, participants are asked to determine which string is the good or acceptable string. The grammatically correct strings in the testing phase are the grammar-generated strings not chosen as exemplars, rather than the exemplar strings from the learning phase. The participants may demonstrate learning by picking the grammatically correct strings at a rate significantly different from chance.

Other methods of assessing implicit learning include the matrix scanning or sequence learning task (Nissen & Bullemer, 1987; Lewicki, Czyzewska, & Hoffman, 1987; Stadler, 1989) and the control-of-complex-systems task (Broadbent, 1977; Berry

Figure 1

Artificial Grammar



& Broadbent, 1984). The sequence learning task requires participants to respond to the location of a stimulus within a four quadrant matrix. Reaction time is the dependent variable in the sequence learning method; participants demonstrate implicit learning when their reaction times to the location of a stimulus decreases. Reaction time of participants significantly decreases when stimulus location is determined by a sequence of complex rules rather than by random selection (Stadler, 1989).

The control-of-complex-systems task requires participants to manipulate a multiple dimensional system in order to reach an experimenter-determined goal. Some of the systems used have included the computer-simulated production of a city transport system (Broadbent, 1977), a computer-simulated sugar production plant and a simulated person-to-person social interaction (Berry & Broadbent, 1984). The ability to maintain specified levels of production (city transport, sugar production tasks) or a specified type of interaction (person interaction task) are the dependent variables in above examples of the control-of-complex-system method.

Both the sequence learning and control-of-complex-systems methods require participant knowledge of complex rule systems, and demonstrate similar results in implicit learning. Participants in the above studies demonstrate knowledge that they are unaware of, in the absence of an explicit desire to gain this knowledge. However, the present study uses the artificial grammar method and so I will focus discussion on that method.

Implicit learning in the context of artificial grammar experiments is considered to be implicit for a number of reasons. The first is that the participants are not deliberately engaged in learning the rules which underlie the order of symbols within the exemplar strings. Because the participants are deceived about the true nature of the experiment, they do not intentionally attempt to understand the rule structure which governs the order of symbols. Typically, they are given instructions that focus on the performance of the masking task. The nature of the instructions and the speed of presentation of exemplars are such that conscious strategies are not helpful or useable in understanding the underlying rule structure.

Learning is also considered implicit because the participants, when asked about the basis of their decisions about grammaticality, are unable to accurately account for their judgments. They cannot explicitly state the rules for grammatically ordered strings of symbols. According to most researchers in this area, the complexity of the underlying grammar is too high for explicit, conscious processing. However, Mathews, et al., (1989) show that participants who receive heuristic data from participants who are participating in an artificial grammar implicit learning task, without seeing exemplars of an artificial grammar, are able to profit from the data. Evidently, participants seeing exemplars are unable to articulate "complete" rule systems which mimic the rule system which created the exemplars, but can articulate partial systems which are helpful. Participants who receive heuristic data performed better than controls but not as well as the participants who provided the heuristics. This finding demonstrates some level of phenomenological awareness of knowledge.

There exists a controversy in the literature concerning the nature of the representation of the knowledge gained from implicit learning. The controversy centers on the differing views on the structure of knowledge gained; three stances on the representation of implicit knowledge are the abstractive, distributive, and fragmentary views (Reber, 1993). In the abstractive view, the participants are said to be learning abstract rule structures (Reber, 1969; Mathews, et al., 1989; Reber & Lewis, 1977). For example, the relationship between elements in the one dimensional implicit learning task in this study is derived from the order of color squares presented to the participant. If the order of color squares were red, yellow, yellow, red, then the participant is thought to represent this knowledge as **Color 1, Color 2, Color 2, Color 1.** In the abstractive view, it would be expected that, if the physical manifestations of artificial grammars were changed, and the underlying grammar remained the same, then there would no adverse effect on implicit learning from the change. Participants should show the same level of performance. The learning is characterized as deep, abstract, and representative of the structure inherent in the underlying patterns of the stimulus environment (Reber, 1989).

The distributive view proposes representation of stimuli as isometric translations of stimulus material into mental representation. The order of color squares would be faithfully represented as appears in "objective" reality, thus red, yellow, yellow, red is represented as **Red, Yellow,Yellow,Red.** There would then be a comparison between mental representations and new stimuli in order to determine the grammaticality of new stimuli. Brooks and Vokey (1991) show evidence that there may be a distributive process as well as an abstractive process at work in making decisions about the grammaticality of items in an artificial grammar implicit learning experiment.

The fragmentary view posits representation of stimuli as smaller "chunks" (Servan-Schreiber & Anderson, 1990) or fragments stored and activated through processing covariations in occurrence (Perruchet & Pacteau, 1990). In artificial-grammar experiments, the fragments are two or three symbol units called bigrams and trigrams, respectively. It is thought that implicit processing measures the variation in occurrence within strings of symbols, and that patterns of this covariance are encoded. Matching the patterns of covariance allows the identification of strings generated using the artificial grammar. In our sample string, red, yellow, yellow, red, the occurrence of red-yellow, yellow-yellow, and yellow-red are noted. Test strings comprised of bigrams that do not occur in the learning phase are rejected as grammatical strings.

Evidence for the primacy of one or the other of these views is not strong. Some theorists (Reber, 1993; Brooks and Vokey, 1991) argue for stimuli-driven representation of stimulus elements. Reber argues that more complex stimuli may lead to abstractive representation, while less demanding stimuli allow for a comparative process like distributive or fragmentary processes. This study does not take a position on the issue of mental representation, except in terms of the coordination of multiple dimensions of stimuli. Specifically, any system of representation must be able to account for the coordination of multiple stimulus dimensions; in the abstractive view, multiple dimensions must be used to construct appropriate rules, and in the distributive view, the salience of multiple dimensions is perceived in order to compare representation of prior stimuli to new stimuli. This issue is raised again in examination of Piaget's concept of multiplicative classification.

Dissociation of Implicit and Explicit Processes

In the literature on implicit learning, two separate systems or processes of learning are posited, the implicit and the explicit. Evidence for dissociation of the two systems rests on two separate arguments, a physical/neuropsychological argument, and an empirical/methodological argument. The physical/ neuropsychological argument demonstrates a split in implicit and explicit systems through evidence garnered from neuropsychological studies of various agnosias such as prosopagnosia (DeHaan, Young & Newcombe, 1987), blindsight (Weiskrantz, Warrington, Sanders, & Marshall, 1974) and amnesic disorders (Knopman, 1991a, 1991b; Warrington & Weiskrantz, 1968, 1974). For example, a person with brain injury to the primary visual cortex may report an inability to see objects within their visual field. When asked to point to an object, or to discriminate between two objects within their visual field, the person may deny the ability to do so. But such persons are able to demonstrate the ability to do exactly these tasks (Weiskrantz, Warrington, Sanders, & Marshall, 1974). This demonstrates a deficit in conscious awareness of the environment that for many researchers corresponds to an explicit cognitive system. When asked to perform tasks that involve some aspect of explicit function, e.g. to discriminate between two objects, persons with this type of brain injury can perform such tasks, but lack phenomenological awareness of this ability. This deficit is not reflected in the ability to perform implicit tasks.

Within the implicit learning literature, studies have contrasted the ability to perform implicit learning tasks with the ability to perform explicit analogues of these implicit tasks in various populations of persons with impaired explicit function (Abrams

& Reber, 1988; Knopman, 1991a; Knopman & Nissen, 1987). Abrams and Reber examined differential performance of college students and psychiatric inpatients on a standard artificial-grammar implicit learning task and an explicit learning task. Both groups were able to complete the implicit task; their performances did not differ significantly. The performance of the inpatients on the explicit task was significantly poorer than that of the college students. As these studies seem to demonstrate, brain injury and/or dysfunction of explicit ability to learn is not reflected in the ability to implicitly function. Because of the difference in loss of ability, it is posited that there exists two different systems/processes at work. One of these systems is affected by the brain injury; the other remains relatively unaffected.

One question that comes to mind has not been addressed in this literature. What does injury to the implicit learning system look like? Such an injury should be possible, given the dissociation of implicit and explicit systems. It seems that an injury to this system, because it generates basic learning processes such as detection of covariation, would be very noticeable. If the effect of such an injury were to leave unaffected explicit function, then the strength of the argument for neuropsychological dissociation of implicit and explicit processes would increase. The opposite would be true if implicit learning injury always lead to explicit deficits.

The empirical/methodological argument for separating implicit from explicit learning rests on the ability to demonstrate two learning systems/processes through the use of methods designed to invoke one or the other system. One example of the use of a method to invoke implicit processes is the artificial grammar. Artificial- grammar implicit learning experiments are designed so their complexity and brevity of exposure to participants militates against explicit understanding of the artificial grammar. Because participants cannot bring to bear explicit learning systems for learning, participants are assumed to use some other system or process to learn the artificial grammar.

Another point in the empirical/methodological argument is the ability to demonstrate interference between implicit and explicit processes. If explicit processes can be simultaneously evoked with implicit processes, so that explicit processes interfere with the performance of implicit processes, then there will be impaired performance on implicit learning tasks. By demonstrating interference, one can demonstrate the existence of both implicit and explicit processes.

One condition that may lead to interference is the type and timing of instruction given to participants in an implicit learning experiment. In general, an instruction set that encourages the use of explicit and implicit processes leads to decreased performance on implicit learning tasks relative to instruction sets that do not encourage the use of explicit processes. For example, participants told of the true nature of an artificial grammar implicit learning task (i.e. told there is a structure to be found within the stimulus elements presented), and encouraged to search for that structure during learning of exemplars performed less well on the subsequent testing phase than did participants who followed the standard procedure (Brooks, 1978; Reber 1976; Howard and Ballas, 1982). It is posited that the explicit search for structure by participants leads to interference with implicit processes, and so performance suffers. Interference occurs because the knowledge gained through explicit processes is not congruent with the structure of the stimulus elements. The rules gained through explicit processes are incorrect.

The timing of instruction set seems to be important in producing interference. If the instruction set illuminates salient features of stimulus elements helpful in learning the underlying rule structure, and this illumination occurs before implicit learning of the underlying rule structure, then there is no interference of implicit learning. Instruction sets that encourage explicit processing after implicit learning has taken place lead to decreased performance (Reber, Kassin, Lewis, and Cantor, 1980).

There exists much controversy on the ability to demonstrate true separation between explicit and implicit processes. Some researchers (Perruchet & Amorin, 1992; Brody, 1989; Dulany, Carlson, & Dewey, 1984) argue that there is no separation of implicit and explicit processes; in essence, explicit learning processes are the default operating processes measured in implicit learning experiments and there is no implicit learning, unless proven otherwise. Others (Reber, 1989, 1993; Mathews et al, 1989) argue for nontrivial learning from implicit processes so that knowledge is gained from a process that is primarily implicit, but not exclusively so. For these researchers, the complete separation of implicit processes from explicit processes is not possible; the key is to show that explicit processes are not sufficient to account for learning.

Do the neuropsychological and methodological arguments lead to a convincing case for the dissociation of explicit and implicit processes? The neuropsychological evidence seems to confirm two fairly encapsulated cognitive processes, with knowledge gained through implicit processes unavailable to explicit processes. However, the appearance of encapsulation of processes in an injured brain and the consequent extrapolation of this encapsulation of processes to uninjured brains is problematic. Brain injury results in a deficit of ability, in which an injured brain functions less efficiently than an uninjured brain. However, an injury which results in a lack of connection between implicit and explicit processes may be the deficit in question. Thus, encapsulation may not occur in the intact brain. The methodological argument is that one can demonstrate, under certain conditions, that there is dissociation between implicit and explicit processes. This argument advances the discourse from the dissociation of implicit and explicit processes, to the conditions in which dissociation occurs. Under experimenter-induced conditions, it seems clear that there is dissociation as evidenced by interference between implicit and explicit processes; whether that experimenter induced dissociation is valid evidence of dissociation of implicit and explicit processes outside of the laboratory is an open question.

There is also the question of evolutionary considerations. The evocation of an implicit learning system that requires such arcane methods to isolate it for study, and which necessarily must work in the presence of explicit cognitive processes makes it especially important to understand how such systems could evolve. The next section examines one theory about implicit learning which utilizes evolutionary biological principles to explore necessary entailments of an implicit learning system.

Development and Implicit Learning

In the literature on implicit learning, there has been little discussion of either ontogenetic development in implicit learning or of the microgenetic development (development within a specific domain) in implicit learning of the underlying structure of a set of stimulus elements that occurs as participants encounter the exemplars in an implicit learning experiment. Reasons for the lack of discussion of development may be an artefact of separation between disciplinary domains (developmental versus cognitive psychology) or sequencing of research programs, (e.g. first demonstration of the phenomenon, and then assessment of particulars). Development may not have theoretical salience for some researchers; for some researchers, development is not an important aspect of the phenomenon under study. However, Reber (1992) has advanced a framework for the relation between implicit and explicit processes and the phylogenesis of both, with implications for ontogenetic development.

Phylogenetic Development of Implicit Learning

Reber (1992) advances a theoretical framework for the examination of nonconscious, implicit cognitive processes and their relation to conscious, explicit processes. It is based on principles of evolutionary biology forwarded by Schank and Wimsatt (1987). It describes necessary entailments or characteristics which result from adopting the stance that implicit processes have been "selected for" earlier than explicit processes in human evolution. Reber's framework is an answer to the question of 'what implicit learning is', rather than how it develops in the individual. However, Reber's discussion does have implications for the study of the individual's development of implicit learning. In this section of the dissertation, Schank and Wimsatt's model of phylogenetic development (development through evolutionary means) is discussed, as well as Reber's use of this model to list necessary qualities of implicit learning in the individual that would confirm the stance that implicit processes are selected before, and thus serve as the basis for, explicit processes.

Schank and Wimsatt (1987) present a model of phylogenetic development called the **developmental lock model**. This model's basic analogy is that of a combination bicycle lock.[1] The wheels of the lock represent developmental stages in the organism. Features which appear at later stages are causally dependent on, or presuppose features from earlier stages. Features which are expressed earlier in ontogenetic development have a higher probability of being required for features which appear later. Earlier-appearing "upstream" features will, on the average, have a larger number of later-appearing, "downstream" features dependent upon them (Schank and Wimsatt, pg 38). The upstream features are features which are evolutionarily older than the downstream ones. The fact that these upstream features have other features dependent on them means that there is less chance that variation (mutation) of upstream features will be successful than variation to downstream features. Phylogenetically older features will appear earlier in ontogenetic development because of the constraints revealed by a developmental lock model.

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[1] The combination bicycle lock is solvable from left to right. The solution to the nth wheel is dependent upon the solution to the n-1 wheel, the wheel immediately to the left of the nth wheel. The wheels of a bicycle lock have 10 positions on each wheel, with one correct solution per wheel. To more closely mimic phenotypic developmental restraints on evolution, Schank and Wimsatt (1987) assume 100 positions per wheel, on the developmental lock, with 10 correct solutions.

Generative entrenchment is defined by Schank and Wimsatt as the relative proportion of downstream features dependent upon the feature of study. Generative entrenchment is a measure of the hierarchical nature of evolution. Newer features are built from alterations of older features, so features that are lower on the hierarchy tend to be older than higher features. Generative entrenchment provides a means of probabilistically determining the relative phylogenetic "ages" of systems of the same or similar kind. Generative entrenchment is the important underlying concept in Reber's framework.

Using the principles of generative entrenchment and the developmental lock, qualities within the individual are discussed as evidence of phylogenetic development of implicit learning (Reber, 1992). Evolution of implicit processes is assumed to predate the appearance of consciousness and conscious, explicit processes. Reber identifies characteristics of implicit learning which should exist in a system purported to be evolutionarily older than an explicit system. These would include the following: robustness, age independence, lower population variance, and relative independence of implicit and explicit ability in cognition.

Robustness. Phylogentically older systems are more capable of function in the face of injury than younger systems because they have resisted injury in the past and have other systems dependent upon them (generative entrenchment). It is posited that organisms with older, upstream features that are fragile in the face of injury do not survive. Implicit learning systems should be more robust in the face of injury than explicit systems because they are posited to be evolutionarily older than explicit systems.

Evidence (Abrams & Reber, 1988; Knopman & Nissen, 1987; Knowlton, Ramus & Squire, 1992) of implicit learning in the face of deficits in explicit ability is extensive.

Age independence. Systems which are phylogenetically older appear earlier in ontogenetic development. Earlier appearing systems are more stable than later systems and show fewer successful variations. Implicit systems are posited to be phylogenetically older than explicit systems; therefore implicit systems should be relatively independent of age and developmental level in comparison to explicit systems. Evidence for age independence of implicit learning (Roter, 1985) has recently been challenged (Maybery, Taylor, & O'Brien-Malone, 1995).

Lower population variance. Older systems must be shared by more individuals in an invariant fashion than younger systems. Implicit learning is an older system; its variance should be less than explicit learning. Research (Reber, Walkenfeld, & Hernstadt, 1991) has demonstrated less variance in performance of an implicit learning across participants than in an analogous explicit learning task.

Relative independence of implicit from explicit ability. Because implicit systems have developed earlier than explicit systems, the manifestation of these two systems must be relatively independent. For example, performance on a IQ test is significantly related to performance on an explicit learning task, but is independent of performance on an implicit task (Reber, Walkenfeld and Hernstadt, 1991).

If implicit learning can be shown to possess the above characteristics, then the evidence would support the contention that implicit learning processes preceded explicit learning processes in phylogenetic development. However, within the above theory are a number of tacit implications. There is the implication that implicit learning, in the individual, is a innate, biologically constrained system and its appearance occurs early in ontogenetic cognitive development. It is explicitly stated that there will be relative age independence in the exhibition of implicit learning; since age differences are often used as the empirical equivalent of ontogenetic developmental change, this implies that there is no developmental change. Its robustness implies that it is rather insensitive to perturbation from the environment. Because it is innate, it is relatively invariant across populations. Finally, an important distinction is that the mechanism of learning which is implied to be biologically constrained, not complex knowledge itself. Thus, it seems, the ontogenetic development of implicit learning is not an appropriate domain of study.

Other than Reber's theory, there seems to be no hypothesis of the individual's development of implicit learning within the implicit learning literature. It has been argued that, according to the evolutionary principles cited in defense of an biologically constrained model of implicit learning, there need not be a developmental aspect to implicit learning (Reber, 1992; Roter, 1985). However, if implicit learning is an innate function of the brain, it does not necessarily follow that implicit learning does not change over time in its manifestation, or that its development should not be studied. Biologically constrained development of secondary sexual characteristics in humans occurs according to a timetable determined by both genetic and environmental factors. Change and development could occur in implicit learning within the model proposed by Reber, and still uphold the evolutionary biological principles cited. Finally, one must question the connection between phylogenetic development and ontogenetic development of implicit learning. The expectation that ontogenetic development will parallel phylogenetic development such that characteristics that occur earlier in phylogeny will also occur earlier in ontogenesis does not take into account processes of acceleration and retardation (Gould, 1977). The appearance of implicit learning as a cognitive ability may occur later in ontogenetic development of humans than would be expected from Schank and Wimsatt's hierarchical theory. Because the majority of research in implicit learning has been done by cognitive psychologists using adult participants, it seems that the question of ontogenetic development within the individual has been superseded by the question of the qualities and limits of implicit learning in adults.

Social and Developmental Aspects of Implicit Learning

At this point, it may be helpful to summarize the past discussion on implicit learning and development and lay out a plan for future discussion. Past research on implicit learning has been conducted in a cognitive psychological tradition. Because of individualistic and subjectivist reduction within implicit learning research, emphasis has been placed on the individual as the unit of analysis, isolated from social and developmental influence. Within the implicit learning literature, principles adapted from evolutionary biology to account for phylogenetic development seem to militate against ontogenetic development of implicit learning. Implicit learning is posited as a fundamental root process (Reber, 1993), and investigation has centered on implicit learning as a singular phenomenon. Because of these beliefs, implicit learning is presented as if it were a non-developmental process of mind, impervious to the influence of social and cultural factors in its manifestation.

In this study it is proposed that, to explain or examine implicit learning, research must turn away from individualistic and subjectivist reductions toward a more inclusive theoretical stance on the individual within a cultural system. This study starts from the premise that there is development in implicit learning, and that there are social and cultural influences on the manifestation of implicit learning. Taking these two statements as givens, the question becomes how can development and social and cultural influences in implicit learning be measured?

Measurement of Development of Implicit Learning

To show ontogenetic development of implicit learning at the simplest level, there must be demonstration of systematic change in implicit learning across individuals. If this change can be seen to occur as a function of time or of some mechanism, then this change is said to be developmental. Change can be quantitative or qualitative in nature, so that one gains more or less of an ability as a function of developmental change (quantitative change), or one shows a difference in ability (qualitative change). One line of research in implicit learning has attempted to measure development in implicit learning (Roter, 1985; Reber, 1993); in this line there has been no evidence of change in ability to implicitly learn from childhood to adulthood. The criterion of change in ability to implicit learn has been quantitative; no difference between children between 5-10 years of age and adults has been measured in mean number of correct responses to recognition of grammatical versus nongrammatical symbol strings (Roter, 1985) or in reaction time to the location of a stimulus (the "Catch Max" research method, reported in Reber, 1993). In this study, a different method of measuring development in implicit learning, one that seeks to demonstrate qualitative change, is proposed below.

One- versus Two-dimensional Implicit Learning

Past explorations in implicit learning have used rule systems that vary in only one dimension or quality. Some ways in which this covariance has been manifested are as changes in letters in a string of symbols in artificial grammar implicit learning experiments (Reber, 1967; Servan-Schreiber & Anderson, 1990; Mathews et al., 1989), changes in numbers in a string of symbols in an artificial grammar implicit learning experiment (Cantor, 1980), and the location of a stimulus within a matrix (Lewicki, Czyzewska & Hoffman, 1987; Stadler, 1989; Willingham, Nissen & Bullemer, 1989). In the Roter (1985) artificial grammar study on the development of implicit learning, variation in the shape and color of symbols (blue square, yellow triangle, red circle, green diamond, or blue "house", yellow "arrow", red "packman", and green "tree") were used; however, since either the dimension of shape or color could be used to solve the artificial grammar, Roter's study can also be considered to have used only one dimension.

Implicit learning studies that use one dimension cannot assess qualitative change over time in the ability to demonstrate implicit learning, because there is no qualitative change within the stimuli to be learned. Only differences in the amount of learning can be assessed. It is posited here that a two dimensional variation in symbols, generated from an artificial grammar in which both dimensions are salient in generating strings, is qualitatively different from a one dimensional artificial grammar. The qualitative difference is that implicit learning of a two dimensional artificial grammar would require the simultaneous coordination of two dimensions to accurately learn a rule system that would result in correct implicit knowledge.

Prior research (Lewis, 1992) using one and two dimensional artificial grammars in implicit learning has demonstrated differences between adults and 5 year-olds in the ability to learn two dimensional artificial grammars. As stated earlier, no differences between adults and children have been found in implicit learning of one-dimensional artificial grammars. In the Lewis (1992) study, the same artificial grammar (Figure 1) was used in the one and two dimensional assessments of implicit learning; the single dimension of color was translated into two dimensions of color and shape (Table 1). By keeping the same underlying artificial grammar, differences in ability to implicitly learn one and two dimensions can be attributed to the coordinations required to learn in two dimensions versus one dimension. This study will replicate this prior research using this one and two dimensional artificial grammar paradigm.

Table 1 - TRANSLATION TABLE

ELEMENT	COLOR	COLOR & SHAPE
A	BLUE	BLUE TRIANGLE
B	RED	RED SQUARE
C	GREEN	RED TRIANGLE
D	YELLOW	BLUE SQUARE

Inhelder and Piaget (1964) examined children's ability to simultaneously coordinate two or more dimensions in their work on the development of logic in the child. This research, explored in greater detail in the next section, demonstrates qualitative developmental change in children between five and nine years of age in the ability to simultaneously coordinate two or more dimensions. Inhelder and Piaget's work in this area investigated explicit ability to simultaneously coordinate two dimensions. Examination of the ability for children to implicitly and explicitly coordinate two dimensions will help to unpack possible connections between implicit and explicit processes as well as highlight developmental change in implicit learning.

Multiplicative Classification

Piaget's concept of multiplicative classification has relevance for a discussion of the differences between one and two dimensional artificial grammars. Inhelder and Piaget (1964), in The Early Growth of Logic in the Child, introduce the concept of **multiplicative classification**. Multiplicative classification is classification of objects which can be divided into different classes based on two or more attributes. If we have a set of elements, like red and blue squares and circles, they can be divided into shape classes (circles and squares), and color classes (red and blue). Inhelder and Piaget found that children of 8-9 years are able to simultaneously coordinate these dimensions in order to manipulate materials which have multiple attributes, and are able to explain the reasons behind their manipulations. Inhelder and Piaget tested children from 4-9 years in their ability to solve problems which require this ability.

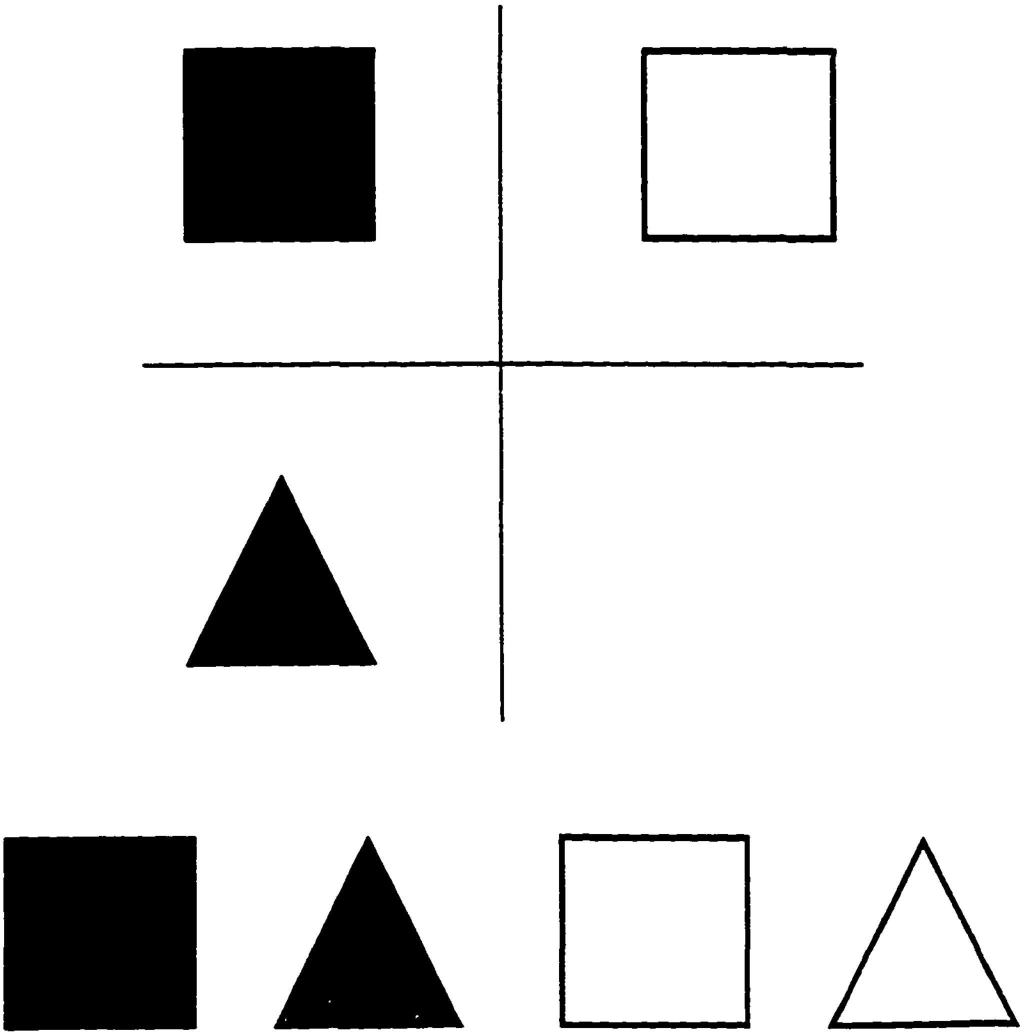
Inhelder and Piaget found children between four and five were able to coordinate two or more attributes at about a 45% success rate and between 8 and 9 years at about a 84% rate. The age range in this study was chosen because, as a part of explicit cognition, the ability to coordinate two differing dimensions is thought to develop between the ages of five and nine years (Piaget, 1963 p 352).

Inhelder and Piaget (1964) used a matrix completion task to assess the ability of children to coordinate various multiple classifications. The experiment consisted of eight matrices. Four of the matrices had 3 symbols which were related to each other in 2 dimensions, color and shape, shape and number, and color and orientation. The 3 symbols were arranged so that there was room for one more symbol (See Figure 2). Six possible choices for this symbol were given to children for each problem. One of these choices was correct, and the other 5 served as distractors. The other four matrices had three symbols which were related in three dimensions. Here also, there was room for one more symbol. Eight possible choices were given for this symbol for each of these matrices.

For all of the problems, each choice was presented, one at a time, and the child was allowed to place them in the matrix. The child was asked to find the correct symbol, justify their placement, and judge whether one or two other symbols might fit in better. If the child were able to chose the correct symbol, explain why they had made that choice in operational terms, and did not change solutions, then they satisfied Piaget's criteria for a correct solution.

Figure 2

Example of Matrix Completion Task



An operational solution showed that children understood and justified their choices by showing the 2 or 3 attributes involved in correct solutions.

> GRA (7,3) chooses the yellow apple at once "because these are the same but of different colours (indicating the vertical direction) and these are of the same colour (indicating the horizontal direction).-- Could I choose any of the others?-- The red apple, but it does not fit in very well, because there is a red flower and a red apple on top; you'll have a yellow flower and a red apple at the bottom. It's better to have a yellow flower and a yellow apple ."
> (Inhelder & Piaget, 1964, p. 164)

GRA indicated both the dimension of shape (flower v apple) and color (red v yellow) impacted on GRA's decision to choose the yellow apple.

Piaget hypothesized that children learned first to answer these type of questions correctly because of the perceptual symmetries of matrices, rather than a true understanding of the nature of classes and how the matrices could be solved by using multiplicative classification. This would become apparent when the children were asked to justify their choice. Children who solved the matrix using perceptual symmetries typically limited their justification to one attribute of the chosen symbol.

> VUA (4;5) correctly chooses the small circle for the practice item .... "Why?-- Because there are two squares." But, when asked "Could one put anything else there?", she replies immediately "Yes the small square is better. -- Why?-- Because then it is the same (identical to the (symbol) above it)."
>
> (Inhelder and Piaget, 1964, p.163)

The ability to coordinate these multiple attributes is the underlying set of operations behind successful conservation. Piaget suggests that there is an intermediate stage in which children are able to get the correct answer, but are unable to justify their answer.

Piaget's research in multiplicative classification may be described as conscious coordination of two dimensions because the matrix completion task requires the child to be aware of the problem space, voluntarily choose to solve the task, and to explain why they have chosen to solve the task in the manner they have chosen. These qualities would seem to indicate conscious mental activity, especially during Piaget's use of the clinical method. This method would require cognizance of the coordination of two dimensions; otherwise the children could not adequately and operationally explain the reasons for their choice. This study required that the participants nonconsciously coordinate two dimensions in order to solve a two dimensional implicit learning task.

It also compared their ability to solve a one dimensional implicit learning task of the same underlying complexity.

Social and Cultural Effects on Implicit Learning

Whether there are social and cultural effects on implicit learning is an unasked question, not only because of the emphasis on the isolated individual in cognitive psychology and implicit learning research, but also due to long-held assumptions about the appropriate population for research (Reid & Kelly, 1994). In the search for cultural differences and similarities in other areas of psychology, a primary research tool is the cross-cultural examination of the phenomenon under study. Cultural differences have been noted in "basic" cognitive research in memory (Cole, Gay, Glick & Sharp, 1971, Wagner, 1981). These cultural differences in performance on memory tests have been hypothesized as greatest in tasks that require "deliberate use of mnemonic strategies" (Rogoff & Mistry, 1985), and least in tasks that require little deliberate strategy (Wagner, 1981). Empirical evidence for these differences are mixed (Rogoff & Mistry, 1985). A similar hypothesis could be extended for implicit and explicit learning. Explicit learning processes are thought to use deliberate strategies while implicit processes rely less on conscious strategies. The beginnings of a possible test (Reber, Walkenfeld, & Hernstadt, 1991) show wider variance in performance on explicit tasks than on implicit tasks within a single culture. No study of implicit learning has been conducted across cultures. Cultural differences in the United States may not be large enough to affect the manifestation of implicit learning; elements of a culture that may be thought to affect the implicit learning of an artificial grammar (e.g familiarity with written language, direction of reading (left-right versus right-left), differing forms of classification) may not vary enough in the U.S. to make a cross-cultural comparison of implicit learning feasible.

Research on social effects, such as the effects of peer interaction on cognition, can be more easily studied within the U.S. For the present study, peer interactions were chosen as an area in which social effects on implicit learning could easily be assessed. In interactions with adults or more capable peers during problem solving, children have shown a higher level of potential development than when engaged in independent problem solving (see research on the zone of proximal development; Vygotsky, 1978). Peer interactions, interactions between equals founded on bilateral respect, and allowing for negotiation of mutually reciprocal intentions (Bearison, 1991), also have effects on performance of children on tasks measuring cognitive ability (Doise & Mugny, 1984; Doise & Mackie, 1981). The effects of peer interaction on explicit cognition and the implications for implicit learning are discussed in the next section.

Social Interaction and Conscious Cognition

Social interaction has long been considered a necessary condition for cognitive development (Piaget, 1965, 1971; Vygotsky, 1978; Baldwin, 1897). In Piagetian theory, constructivist and organismic underpinnings (Overton & Reese, 1973) require social interaction; the nature of cognitive development is such that the effects of interactions with others force the child to regulate cognition. Regulation, a requisite of all biological systems, specifically cognitive regulation in this context, can drive a child to new, higher forms of cognition. Piaget's theory of equilibration describes this process of "optimizing" regulation resulting from social interaction.

Piaget's (1975/1985) theory of equilibration characterizes the development of knowledge as a dialectical process of re-equilibration, between organism and environment (equilibrium > > > disequilibrium > > > equilibrium). Piaget discusses this dialectic in the context of a non dyadic interaction between organism and environment; in *Biology and Knowledge* (Piaget, 1971) he asserts this dialectical process in the context of interindividual interaction. Equilibria occur between subject and object at the level of material action, between cognitive subsystems, and between these subsystems and the total system of which they are a part (Piaget, 1975/1985, p8). Disequilibration is the perturbation of these equilibria through cognitive conflicts between assimilations and accommodations and incongruity between affirmations and negations. These conflicts can occur in the context of social interactions between the child and others. In Piaget's earlier work on moral development (Piaget, 1932/1965), the mechanism of development of rational morality is the conflict between peers in interaction. Exchanges between peers forces the child to decenter, to step away from the child's own cognition, and to take into account the perspective of others. As the child reestablishes cognitive equilibrium (reequilibration), the child restores congruity and resolves conflict in the child's own cognition. Progress is only found when reequilibration leads to new and more powerful "higher" form of equilibration.

Other researchers in the Piagetian tradition provide further insight into social peer interactions (Doise & Mugny, 1984; Perret-Clermont, 1980; Doise & Mackie, 1981; Bearison, Magzamen, & Filardo, 1986; Ames & Murray, 1982). Piaget asserted that cognitive development occurs in the context of cooperative relations, relations between equals in which elements of authority do not intervene (Sinclair, 1987). Children do not make genuine cognitive progress if adults or older children impose their views. For peer interactions to be effective, they must be truly interactive and engage children in conflict. By this I mean there must be some kind of disagreement which requires negotiation between the peers. They must be interactive in the sense that each child must coordinate action with their partner, not merely work in the presence of another child.

> "Thus, when several children have to complete a collective drawing,... side by side, there is less need to coordinate actions than when they must together draw a map of their village.... Only in the latter case could progress due to interaction be expected" (Doise & Mugny, 1984).

The sociocognitive conflict, and the resolution of this conflict, is what allows children to reach a higher level of understanding. Doise and Mugny attribute the appearance of novel abilities in the child to the disruption of the child's accustomed cognition by external influences. This disruption must be resolved, and the search for resolution leads the child to create and integrate new cognitive structures. Doise and Mugny cite Piaget's work on equilibration as a possible description of the process.

Sociocognitive conflict between two children can lead to disequilibration within each child through conflict between the centrations of two children. The child is forced, because of the social presence of the other child, to acknowledge the conflict and to assimilate the incongruity between the child's internal cognition and the cognition of the other child, as represented by the other child's verbalization and behavior. When children are alone, they will repress cognitive schemes and observables (Piaget, 1975/1985, p115) that cannot be assimilated into their present cognitive structures. Conflicting cognitions of other children cannot be repressed as easily; it "cannot be as easily denied as a conflict resulting from successive and alternating individual centrations" (Doise and Mugny, 1984, p.28) and therefore the child in sociocognitive conflict must confront this incongruity.

Reequilibration of the child's cognitive system occurs. This reequilibration may or may not take into account the perspective of the other, conflicting child. It is the conflict that is important; it is not necessary that the other child has a more correct understanding of external reality. The conflict need not be between a child and a person at a higher level of cognitive functioning, as is the case in the zone of proximal development (Vygotsky, 1978). It is the very fact that the child must resolve the contradiction of conflict with another that forces the child to face the contradiction in the child's own reasoning (Bearison, 1991; Smedslund, 1966 as related by Doise & Mugny, 1984). Thus a child can show optimizing reequilibration, reequilibration that leads to new and better forms, (Piaget, 1975/1985), in social interaction with a child of equal cognitive ability, if there is a sociocognitive conflict (Doise & Mackie, 1981).

This reequilibration is believed to describe what happens when a child is interacting with a peer in a conservation task. For example, in a volume conservation task, a child may centrate on one dimension of the problem, like height, at the expense of other dimensions like width, and thus cannot conserve. The presence of a peer, working on the problem with the child, forces the child to socially and cognitively decentrate. During this process of decentration, the child examines previously held ideas, such as centering on one dimension of the conservation task. If the child can grasp the contradiction in cognition during reequilibration, and simultaneously coordinate two or more dimensions, then the child experiences an optimizing reequilibration, and demonstrates conservation of volume. As conservation is served by the same operations which underlie the coordination of multiple attributes (Piaget & Inhelder, 1941/1974; Inhelder & Piaget, 1969), we should see a similar effect in the solving of multiplicative classification matrices, and possibly in the implicit learning of two dimensional artificial grammars.

Can such an optimizing effect occur in peer interactions in implicit learning? Most of the researchers working in peer social interactions make assumptions concerning the effect of peer social interaction. One assumption is that the peers are consciously aware, at some level, of their knowledge. In fact, it makes little sense to describe their interaction in any other way. Child A, while interacting with Child B, has some knowledge X. Child A must be aware of knowledge X in order to have a sociocognitive conflict with Child B, who possesses and expresses knowledge different from Child A. The children can and do repress this contradiction if they cannot assimilate it (Doise &

Mugny, 1984, pg 28). It is an unstated given that peers are conscious of their interaction because social interaction, by definition, must involve two or more people who are actively and mindfully interacting with each other.

Another assumption is that the child must become aware of sociocognitive conflict, at some level. The child may or may not be aware of the conflict while they are ignoring the contradiction in their cognition. It certainly does not impact on their cognition or cognitive ability. But there is the implication that the child becomes aware of the conflict and/or the contradiction and actively moves to resolve it, at the time of integration of rival centrations into the child's cognitive structure (Piaget, 1975/1977; Rogoff, 1990). Piaget refers to the process of reflecting abstraction, which is a "sense of a cognitive reconstruction or reorganization (more of less conscious) of what has been transferred" (Piaget, 1975/1977, p 35), by the child when integrating new centrations into their cognitive structure.

The level of awareness becomes important in understanding the effect of social interaction in general, when one asks the question of the effect of social interaction on implicit learning. In implicit learning, one does not have phenomenological awareness of one's knowledge of an artificial grammar ("knowing that"). Yet one can demonstrate this knowledge ("knowing how"), at some other level. It is knowing how to distinguish grammatical and nongrammatical strings that is accepted as learning in implicit learning experiments.

In a Piagetian framework, does one have to be phenomenologically aware of one's knowledge to engage in a process of optimizing reequilibration? When Piaget refers to reflecting abstraction, what does he mean by "more or less conscious?" Through peer interaction in implicit learning of artificial grammars, these questions can be addressed. Because implicit learning is thought to result in knowledge that is outside of phenomenological awareness, there can be a test of the level of awareness required to demonstrate the optimizing effects from peer social interaction. This study examined the effect of peer interaction on implicit learning of one and two dimensional artificial grammars.

Peer Interaction and Explicitness of Learning

Will children engaging in peer interaction while working on an implicit learning task have more explicit knowledge of the artificial grammar? It might be argued that, when participants engage in interaction around an implicit learning task, there is a need to make explicit the products of implicit learning. When working alone, the purpose of attempting to solve an implicit learning task is to get the correct answer. In a classic artificial-grammar implicit learning experiment, participants are not asked the reasons for their choice; their intuitions about the nature of the grammar remain unarticulated. When it becomes necessary to articulate these intuitions, as occurs when participants are asked to provide instructions for others (Mathews et al., 1989), participants can make explicit some part of their knowledge. It is clear from this research that participants can articulate some knowledge gained through (presumably) implicit means.

In Mathews et al. (1989), participants working alone in an artificial-grammar implicit learning experiment were able to articulate partial rules that enabled naive participants to demonstrate learning. As the experimental participants increased their ability to demonstrate implicit learning, their ability to articulate also increased, although participants' ability to articulate always lagged behind the ability to show implicit learning. Naive participants' learning always lagged behind experimental participants' implicit learning. Could the instruction of creating explicit rules for naive participants have an effect on the "explicitness" of the knowledge of the artificial grammar? If so, then interaction with a peer may also require participants to gain more explicit knowledge concerning the artificial grammar under study. As any graduate student knows, there is a very large difference between knowing something when one is alone at home, and being able to articulate that knowledge to others. In any interaction, there is communication between those participating in the interaction. A peer interaction may force participants to articulate their knowledge for their partner in ways that are not required by participants working alone.

One possible measure of explicit knowledge useful in a classic artificial- grammar implicit learning experiment could compare the articulations concerning the artificial grammar by interacting peers, who must speak to one another during the course of their interaction, to participants who are working alone. If interacting participants could give more rules about the grammar than participants working alone, then the knowledge gained by interacting participants could be more explicit than knowledge gained by those working alone. The accuracy of the knowledge given by participants is important here; the measure of this knowledge is found in its accuracy. Accuracy of knowledge can be evaluated in artificial-grammar implicit learning in two ways. The first is whether the articulations concerning the artificial grammar are indicative of the grammar. In other words, are the articulations grammatically true of this grammar? For example, if a participant says that one rule determining the order of symbols in a string is "Green squares always come first in line", and if green squares do indeed come first, then this articulation is a grammatically-true articulation. The importance of this accuracy is obvious; if the participant can articulate a response that indicates learning of the artificial grammar, then the experimenter can be certain that this is explicit knowledge held by the participant.

The second way of evaluating accuracy of articulation of explicit knowledge is to assess whether the participant behaves as if the articulation is true. If a participant says that one rule determining the order of symbols in a string is "Green squares always come first in line", and if strings with green squares are always chosen as grammatical strings, then the articulation is behaviorally true, at least for this participant. The accuracy of articulation about one's own behavior is important because it here indicates the amount of explicit, conscious control over choice by the participant. If the participant can describe the reasons for choices, then much of the knowledge held by the participant must be accessible to phenomenological awareness. In essence, the participant explicitly knows knowledge X and acts upon it. If the participants cannot describe their actions, if their articulations are not behaviorally true, then it must be assumed that the knowledge held by the participant is not accessible to phenomenological awareness. Another assumption might be that there is some strong dissociation between the explicit and implicit, so that participants must create some story to explain actions that are outside of phenomenological awareness.

This study seeks to discover if social interaction, as instantiated by peer interactions, has an effect on explicit knowledge gained by participants. This explicit knowledge is broken into knowledge about the artificial grammar (grammatically true articulations) and knowledge about the participant's own behavior (behaviorally true articulations).

Hypotheses

1a. There is implicit learning of a one-dimensional artificial grammar, that is largely independent of age, so that the mean performance of children between 4 and 10 years of age will significantly differ from chance. This hypothesis will be tested by comparison between mean performance on a one-dimensional implicit learning task and expected performance if participants guess on the implicit learning task.

b. There is implicit learning of a two-dimensional artificial grammar, that is independent of age, so that the mean performance of children between 4 and 10 years of age will significantly differ from chance. This hypothesis will be tested by comparison between mean performance on a two-dimensional implicit learning task and expected performance if participants guess on the implicit learning task.

2. There is a significant difference in the ability to demonstrate implicit learning between one- and two-dimensional artificial grammar for all participants, so that they will be able to perform one-dimensional tasks better than two-dimensional tasks. Each participant will engage in one- and two-dimensional implicit learning tasks. Differences in performance between the two tasks will be assessed.

3a. There is **no** significant difference in the ability to demonstrate implicit learning of a one-dimensional artificial grammar across developmental level, when working alone. Developmental level is measured by a pretest, which separates participants into coordinators, children who are able to simultaneously utilize two or more dimensions to solve a task, and noncoordinators, who do not yet have this ability. Noncoordinators of two or more dimensions will perform as well as coordinators on one-dimensional implicit learning tasks.

b. There is a significant difference in the ability to demonstrate implicit learning of a two-dimensional artificial grammar across developmental level, when working alone. Noncoordinators of two or more dimensions will **not** perform as well as coordinators on two-dimensional implicit learning tasks.

4. There are significant differences between children working alone and children working with a peer in a dyad in their ability to demonstrate implicit learning of one- or two-dimensional artificial grammars, so that noncoordinators working together will

perform better than noncoordinators working alone. In this hypothesis, the effect of peer interaction is assessed by comparing the performance of dyads of coordinators and noncoordinators against the performance of coordinators and noncoordinators working alone, on implicit learning tasks of one and two dimensions.

5a The articulations concerning the nature of the grammars will be more indicative (grammatically-true) of the true nature of the artificial grammar for dyads than for non dyads.

b. The articulations indicating their own behavior during the testing phase of the implicit learning tasks will be more accurate (behaviorally-true) for dyads than for non dyads.

METHOD

Participants

The participants in this study were 87 children from 5 years of age to 10 years of age. These ages were chosen because, in most studies of multiplicative classification, these ages bracket the period in which children learn to coordinate two dimensions (Inhelder & Piaget, 1964). The sample in this study was mixed in ethnicity (34 African Americans, 35 Latino/as, and 18 Whites) and gender (39 boys, 48 girls). The sample was collected from public and parochial schools in New York City (n=60) and in a school district in Western Oregon (n=27). The grades of children ranged from kindergarten (n=5, mean age=6:1 years), first (n=23, mean age=6:0 years), second (n=13, mean age=7:0 years), third (n=20, mean age=7:9 years), fourth (n=21, mean age=8:7 years), and fifth grades (n=5, mean age=9:7 years).

Based on the demographics of the neighborhoods of the schools, the SES of the participants was lower middle class to middle class. The children were divided into two conditions in order to assess the effects of peer interaction: an ALONE condition in which they worked alone, and a DYAD condition is which they were placed into dyads.

The dyads in the peer social interaction phase of the study were matched for gender, ethnicity, and grade. All of these variables were held the same for each dyad. In this sample, no gender and ethnic effects were found on task performance. Similarly, in a past investigation of implicit learning (Lewis, 1992), no significant gender or ethnic effects in ability to implicitly learn one or two dimensional stimuli were found.

Table 1

Participant Grade and Coordinator/Non Coordinator Breakdown

Grade	Non Coordinator	Coordinator	TOTAL	Mean Age
Kindergarten	4	1	6	6:1
First	17	6	23	6:0
Second	6	7	13	7:0
Third	9	11	20	7:9
Fourth	4	17	21	8:7
Fifth	1	4	5	9:7

Kendall Tau-b = .38, $p < .001$

There is a significant difference across grade in the proportion of noncoordinators to coordinators.

Materials

Pretest

Pretest materials

A set of 10 matrix completion problems and 4 pieces per problem.

A pretest task was constructed in order to establish a baseline of ability to explicitly coordinate two or more dimensions in children between 4 and 10 years old. The pretest consisted of a set of 10 matrices, similar to those used by Inhelder and Piaget (1964) to assess the ability to use multiplicative classification. The pretest matrices used shape, color, and size as the varying dimensions. Three matrices were each divided into four quadrants, with the lower right quadrant empty of a symbol (See Figure 2). The upper quadrants contained one symbol each, and they were related to each other though a change in one dimension. For instance, the upper left quadrant in Figure 2 holds a dark square, and the lower left holds a dark triangle. The upper right holds a light square, and the empty, lower right quadrant can hold one of four pieces presented to the child. Seven matrices were divided into 3 X 3 matrices, with 4 empty sections and 5 filled sections. All four pieces presented to the participant must be placed into the matrix. A list of all matrices and pieces presented to the participants is found in Table 3.

Table 3

Pretest Cards and Pieces

Id No.	Card	Pieces	Answer
1	MBT MYT MBQ ___	MBT, MYT, MBQ, MYQ	___ ___ ___ MYQ
2	SYC SBC LYC ___	SYC, SBC, LYC, LBC	___ ___ ___ LBC
3	SYC LYC SYT ___	SYC, SYT, LYC, LYT	___ ___ ___ LYT
4	MYT MBT ___ MYQ ___ MRQ ___ MBC ___	MRT, MRC, MYC, MBQ	___ ___ MRT ___ MBQ ___ MYC ___ MRC
5	SYT ___ SYC MYT MYQ ___ ___ ___ LYC	SYQ, LYQ, LYT, MYC	___ SYQ ___ ___ ___ MYC LYT LYQ ___
6	SBQ ___ SYQ MBQ ___ MYQ ___ LRQ ___	SRQ, MRQ, LBQ, LYQ	___ SRQ ___ ___ MRQ ___ LBQ ___ LYQ
7	MYT MYQ ___ ___ MRQ ___ MBT ___ MBC	MRT, MRC, MYC, MBQ	___ ___ MYC MRT ___ MRC ___ MBQ ___
8	MYT ___ MYC SBT ___ SBC ___ LRQ ___	LRC, LRT, SBQ, MYQ	___ MYQ ___ ___ SBQ ___ LRT ___ LRC
9	LRQ ___ LRT ___ MBC ___ SYQ ___ SYT	MBT, MBQ, LRC, SYC	___ LRC ___ MBQ ___ MBT ___ SYC ___

Table 3 con't

10	LYQ ___ SYQ LRT ___ SRT ___ MBC ___	SBC, LBC, MYQ, MRT	___ MYQ ___ ___ MRT ___ LBC ___ SBC

The first letter designates the size (Small, Medium, and Large), the second letter designates the color (Blue, Red, Yellow), and the third letter the shape (Triangle, SQuare, Circle). The small shapes were 1" in diameter (circle) or side (triangle, square), the medium were 1.5" in diameter and side, and the large were 2" in diameter and side.

Implicit Learning Tasks

Implicit learning task materials

1) a set of non toxic magic markers, red, blue, green and yellow for the ONE dimensional task and blue and red for the TWO dimensional task.

2) nine exemplar cards with a single grammatical string on each card. (See Table 4)

3) Thirty test cards with two strings, one grammatically correct, the other containing one error of grammaticality. (see Table 5)

Two implicit learning tasks were designed to assess the ability of children to implicitly learn an artificial grammar: a one-dimensional implicit learning task, and a two-dimensional implicit learning task. Each task consisted of rows of colored squares (one dimension) called strings or strings of colored triangles and squares (two dimension). The strings in both tasks in this study were generated from a single artificial grammar (See Figure 1). The strings varied from 2 to 5 symbols in length, and there were 24 grammatically correct strings generated by this grammar. Nine strings were chosen as exemplars, for presentation (3 times for each string) in the learning phase of the study. Fifteen strings were matched with strings of the same length with one error of grammaticality as forced-choice tests.

One-dimensional task. The one-dimensional task used strings with symbols that varied in color; shape was held constant. The four colors used to generate symbols were

Table 4

Exemplar Strings for One- and Two-Dimensional Implicit Learning Tasks

	Dimension	
ID No.	One (COLOR)	Two (COLOR & SHAPE)
E1	R B	RS BT
E2	B Y	BT BS
E3	R Y Y	RS BS BS
E4	B G R	BT RT RS
E5	R G G B	RS RT RT BT
E6	R G Y R	RS RT BS RS
E7	R G Y G Y	RS RT BS RT BS
E8	R Y G G Y	RS BS RT RT BS
E9	B G G G Y	BT RT RT RT BS

R=red, B=blue, Y=yellow, G=green, RS=red square, RT=red triangle, BS=blue square, BT=blue triangle

Table 5

Test Strings for One- and Two-Dimension Implicit Learning Tasks

	Dimension	
ID No.	One (COLOR)	Two (COLOR & SHAPE)
T1	B R B G	BT RS BT RT
T2	R G B Y G B	RS RT BT BS RT BT
T3	R Y R R B R	RS BS RS RS BT RS
T4	B G G B G Y	BT RT RT BT RT BS
T5	Y G Y Y R G Y Y	BS RT BS BS RS RT BS BS
T6	R B G Y R Y G Y	RS BT RT BS RS BS RT BS
T7	R Y G B R Y G R	RS BS RT BT RS BS RT RS
T8	B G G Y B G Y Y	BT RT RT BS BT RT BS BS
T9	B G G G B G G R	BT RT RT RT BT RT RT RS
T10	R B G Y Y R G G Y Y	RS BT RT BS BS RS RT RT BS BS
T11	R G Y B R R G Y G R	RS RT BS BT RS RS RT BS RT RS

Table 5 con't

T12	R G G G B G G G G B	RS RT RT RT BT RT RT RT RT BT
T13	R G G Y R R G B Y R	RS RT RT BS RS RS RT BT BS RS
T14	R Y G G R R Y G G G	RS BS RT RT RS RS BS RT RT RT
T15	B G G G R B G G Y R	BT RT RT RT RS BT RT RT BS RS

R=red, B=blue, Y=yellow, G=green, RS=red square, RT=red triangle, BS=blue square, BT=blue triangle

The positions of test strings (top, bottom) were switched for half of the participants. No position effects were noted.

red, green, blue and yellow. The fifteen test strings were matched with strings containing one error, in a two choice forced choice format. The error was dependent on the type of task; in the one-dimensional task, the error was of color.

Two-dimensional task. The two-dimensional task varied both color and shape. Both the one-dimensional and two-dimensional task had the same underlying grammar; the elements of the grammar were translated from the one-dimensional condition to the two-dimensional condition. Color, in the one-dimensional condition was translated into color and shape in the two-dimensional condition. The translation schedule is on Table 1. The artificial grammar was a four element grammar; four colors for one-dimensional task were translated into two colors and two shapes for the two-dimensional task. In the two-dimensional task, the error was of either shape or color or both. The errors were balanced in terms of position of error and, in the two- dimensional task, the number of shape, color, and both shape and color errors. The lists of exemplars and test strings are in Tables 4 and 5 respectively.

Procedure

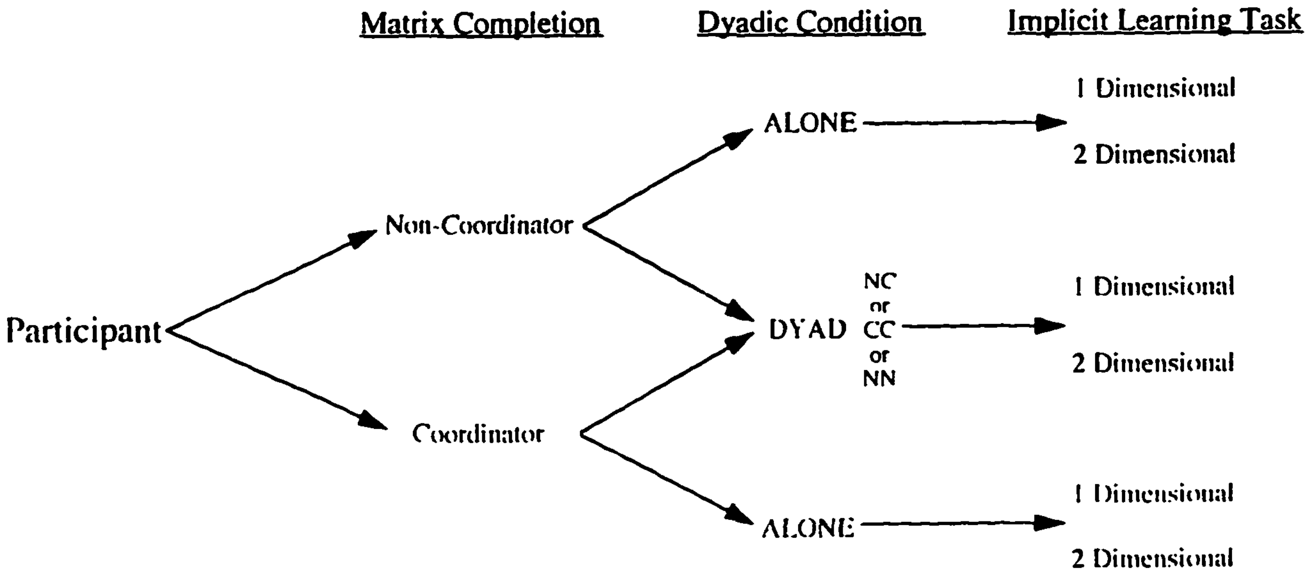
Children from kindergarten to the third grade were asked, in their school classroom by their teachers, to take to their homes a letter explaining the goals of the research (to understand how children learn). The letter requested parental consent or nonconsent, if the child and parent wished the child to participate in the study. All of the children in each class were asked to return the letter, regardless of their parent's or caregiver's decision. Only those children who returned a signed consent form were selected for this study.

Children were escorted from their classroom to a quiet place (typically the library or an unused classroom) by the researcher or a research assistant. All of the children were introduced to the researcher and his assistants by their teacher before leaving the classroom. After making the child comfortable with the researcher and assistants and explaining the purpose of the research (i.e. research about how do children think), the researcher tested the child for knowledge of colors and shapes. All of the children knew what each of the four colors (red, blue, green, yellow) and the three shapes (circles, squares, triangles) used across the entire study, both pretest and implicit learning tasks. None of the children were colorblind. A precis of the entire procedure is presented in the next paragraph, and the experiment is summarized graphically in Figure 3. A more detailed description of each phase of the experiment follows.

Each child was required to complete a series of 10 matrix completion problems. The number of correct completions determined the separation of the total sample into two groups, coordinators (C) and noncoordinators (N). These groups reflect different developmental levels. Children were then placed into one of two conditions, an ALONE condition, in which they completed one and two dimensional implicit learning tasks alone, or a DYAD condition, in which they were paired together to complete one and two dimensional implicit learning tasks while engaged in social interaction. The order of presentation of one and two dimensional tasks was counterbalanced, and no order effects were found in data analysis. The DYAD condition paired participants in one of

Figure 3

Flow Chart of Dissertation Experiment



three possible dyads (noncoordinator and noncoordinator (NN), coordinator and coordinator (CC), or noncoordinator and coordinator (NC)).

Pre-test - Matrix Completion Task

Each child took part in a pre-test to assess their ability to consciously coordinate two or more dimensions. This pretest required each participant to complete a series of 10 matrix completion problems. The dependent variable was the number of correct responses. The maximum score on the pretest was 10 correct, the minimum score was 0. These matrix problems were similar to those used by Inhelder and Piaget (1964) to assess the ability to consciously coordinate 2 dimensions simultaneously. Careful questioning of the children was used to determine whether the participants have a true operational understanding of their coordination. The child was asked the reasons for choosing each piece. If the child chose the correct piece and demonstrated an operational understanding of the reason for that choice, then the matrix was considered a success. Operational understanding was defined by the experimenter as a demonstration of knowledge of the two dimensions used to place the correct piece. For instance, in Figure 2, the child would be considered to have an operational understanding if they mentioned, in answer to the experimenters question, that color and shape determined their choice.

The child was told that he or she would be asked to solve some puzzles. The child was then presented with the first problem, which required the child to coordinate color (blue and yellow) and shape (square and triangle) in order to choose the correct puzzle piece (yellow square). If the child chose the correct piece, then the researcher asked the child why the piece was chosen. If the child gave a correct response, the researcher affirmed the choice, and then presented the next matrix. If the child chose an incorrect piece, the researcher then told the child that the researcher would have chosen a different piece, and explained the reasons for a different choice (e.g. the blues go in this row, and the yellows go in that row; triangles go in this column and squares go in this column). At this point, the researcher asked the child for another choice, and all of the children were able to choose the correct piece, which was the yellow square. The researchers only corrected or affirmed the participants choice for the first matrix. The next matrix was then presented. After the child solved the third matrix, new instructions were given for the balance of the matrices. The child was told that the rest of the puzzles used all of the pieces provided. The full script used in the pretest can be found in Appendix A.

Participants were then organized into groups, according to their performance: successful performance of 70% (7) or more matrix problems classified participants as **coordinators**, while a performance of 40% (4) or less were classified as **noncoordinators**. There was a provision for **intermediates**, who were participants able to complete at least 50% of the matrices, and were unable to correctly articulate their reasons for their choice. During the course of the study, only one child who fit the criteria for an intermediate was found, and so was not included in further analyses. An examination of the total pretest performance for the sample showed that there was bimodal performance. One mode was at 2 correct answers and the other was at 8 correct answers.

Social Context Conditions

The 46 coordinators and 41 noncoordinators were then randomly placed into one of two conditions, an ALONE condition, in which they completed one and two dimensional implicit learning tasks alone, or a DYAD condition, in which they were paired together to complete one and two dimensional implicit learning tasks while engaged in social interaction. The DYAD condition paired participants in one of three possible dyads (NN, CC, NC). The DYAD condition matched children for grade, age, gender and ethnicity. Each child participated in only one condition.

The purpose of placing children in dyads was to give participants the opportunity to discuss the implicit learning task with another person. It was expected that the participants would gain explicit, verbal knowledge of the artificial grammars because they had discussed the implicit learning task with a peer.

Implicit Learning Tasks

All participants, after placement in an interaction condition (DYAD or ALONE), were then given two artificial grammar implicit learning tasks. Participants worked on both a one-dimensional and two-dimensional task. The order of presentation of one- and two-dimensional tasks were counterbalanced in each condition. Each task was broken into two phases, a learning phase and a testing phase.

The one-dimensional task varied color according to an artificial grammar (see Figure 1). This paradigm uses an artificial grammar, a set of rules to govern the order of a string of symbols presented to participants. The grammar generates a finite set of strings called grammatical strings. The experimenter chose a small subset of these grammatical strings as exemplars of the total set. The nine exemplars chosen demonstrated all of the salient rules for grammatical strings. Participants experienced 3 iterations of 9 exemplars for a total of 27 exposures. The two-dimensional task varied color and shape according to the same grammar, for the same amount of exposures.

In the learning phase, the participants were informed that they were taking part in a study of children's thinking. They were instructed to pay close attention to the following rules. The experimenter asked the participants to copy each exemplar card with the magic markers and paper provided. A participant was presented with these exemplars, one string at a time. The participant was not informed of the nature of these strings as exemplars. The exemplars were presented in random order, except for the first card, which was always a 2 element string. The experimenter observed and prompted participants to correct errors in their copies.

This prompt would occur at the end of copying of the exemplar string, and the participant would correct, usually by recopying the string. After the participants had completed their copies, the exemplar materials and copies were removed. As stated above, those participants in the DYAD condition were presented with the exemplars together, and asked to check on the work of their partner.

In the testing phase, after presentation, the participant was told that the strings just copied are examples of special strings which were made by the experimenter's teacher. The participant was shown a test card with a grammatically correct and an incorrect string in a two-choice forced-choice format and was asked to indicate which string was special, like the strings they had copied previously. The participants usually expressed their inability to remember the copied strings, but after reassurance were able to perform. The experimenter recorded their responses. The participants were shown 15 test cards in two iterations, for a total presentation of 30 test cards. The number of correct choices was the dependent variable in the implicit learning tasks. The experimenter then asked the following questions:

1) On a scale of 1 - 5, with 1 being very sure, and 5 being not sure at all, how sure are you of the answers you just gave me? (The experimenter also showed a number line, labelled from 1 to 5.)

2) a. Did you notice a pattern to the shapes and colors that you copied before?
   b. What was that pattern?

3) a. Were there any clues that helped you pick the right answer?
   b. What were the clues?

Those participants in the DYAD condition were asked to try to come to an agreement about their choice of the correct string. They were also told that if they could not agree, then they were allowed to chose different strings. After they had made their choices of correct strings, the DYAD participants were separated in order to answer questions 1, 2, and 3 above. The experimenter then debriefed the participants and discussed the procedure. The responses of the children to these questions were recorded verbatim for future analysis.

Qualitative Measure of Articulations

Articulations about the test strings and participants' thoughts about patterns and clues underlying the test strings observed were elicited in response to the researcher's query about clues and patterns in the strings that the child had copied. If children were unclear in their explanation of the clues or patterns, if any, that helped them to get the right answer, then the researcher asked them to clarify their explanation.

An articulation was operationally defined as the expression of a single idea about the artificial grammar. Thus, "Green squares always come first in the line" counts as one articulation. The analyses on these articulations evaluated the accuracy of each statement as true of that participant's behavior and true about the grammar under study. An articulation is counted as true of the grammar (grammatically-true) if it could account for strings generated by the grammar. According, the above articulation is considered to be untrue. No grammatical string can begin with a green square in the one dimensional grammar used in this study. If a child said that green squares always go first in line, then her choices were examined to determine whether he or she picked strings that begin with green squares. If she followed her own prescription, then the articulation was judged to be accurate about the child's own behavior (behaviorally-true).

Thus, an articulation could be judged false, when compared to the nature of the artificial grammar, but could be judged true, when compared to the child's behavior.

RESULTS

Pretest - Matrix Completion Task

An analysis of the children's responses on the pretest showed that there was a clear separation between performance on the pretest for coordinators and noncoordinators. The coordinators, as a group, had a mean of 8.74 correct, while the noncoordinators had a mean of 3.70 correct. The difference between the coordinators and noncoordinators was significant ($F_{1,85} = 296.49$, $p<.001$).

An analysis was then performed to see if the pretest showed a separation of coordinators and noncoordinators between 6 and 8 years of age. There were differences in the mean ages of coordinators and noncoordinators; the mean age of the noncoordinators was 6 years 9 months, and the mean age of the coordinators was 7 years 11 months. This difference was significant ($F_{1,85}= 24.99$, $p<.001$). There was a positive correlation ($r=.561$, $p<.001$) between the number of correct answers to the matrix completion task and the age in months of the participants in this study. The pretest was posited as a measure of difference in developmental level. As a measure of multiplicative classification modelled on Inhelder and Piaget's (1964) measure, the pretest mirrored the results found in that study. There was a change in ability to coordinate multiple dimensions between 6 and 8 years of age.

Implicit Learning of 1 and 2 Dimensional Artificial Grammars - Hypotheses 1a, 1b

Participants were expected to get a total of 15 correct out of 30 test cards, by chance, in each implicit learning task. For each implicit learning task (one and two dimensions), a 95% confidence interval was calculated via ANOVA to assess whether the mean performance for each dyad condition (DYAD, ALONE), each pretest group (coordinators and noncoordinators) and the total sample was significantly different from chance. In the one-dimensional implicit learning (IL) task, the total sample performed significantly above chance. Coordinators paired with coordinators (CC) in the DYAD condition also performed above chance on the one-dimensional IL task. These were the only groups that performed above chance on the one dimensional IL task. No group performed above chance on the two dimensional IL task. Table 6 summarizes mean performance of each group.

Differences in Implicit Learning of 1 and 2 Dimensional Artificial Grammars-

Hypothesis 2

A repeated measures (Alone/Dyad x Developmental level x Implicit Task (2x2x2)) ANOVA (See Table 7) was run on the number of correct choices on the implicit learning tasks to assess differences in individual performances of participants on one and two dimensional implicit learning tasks. Performance for all participants was lower on the

Table 6

Mean Numbers of Correct Responses to One- and Two-Dimensional Implicit Learning Tasks

One-Dimensional	N	Mean	SD	95% CI for Mean
Alone				
Noncoordinators	17	16.06	3.98	14.01 - 18.10
Coordinators	22	16.27	3.80	14.58 - 17.96
Dyads				
Noncoordinators paired with				
Coordinators	10	16.40	3.53	13.87 - 18.93
Noncoordinators	14	13.86	2.93	12.16 - 15.55
Coordinators paired with				
Coordinators	14	18.36	3.65	16.25 - 20.46
Noncoordinators	10	17.00	3.83	14.26 - 19.74
TOTAL	87	16.78	3.79	15.47 - 17.08

Two-Dimensional	N	Mean	SD	95% CI for Mean
Alone				
Noncoordinators	17	14.76	3.32	13.05 - 16.48
Coordinators	22	16.09	3.94	14.34 - 17.84
Dyads				
Noncoordinators paired with				
Coordinators	10	15.00	2.94	12.89 - 17.10
Noncoordinators	14	14.36	2.68	12.81 - 15.90
Coordinators paired with				
Coordinators	14	14.71	2.61	13.20 - 16.22
Noncoordinators	10	16.00	2.21	14.42 - 17.58
TOTAL	87	15.20	3.14	13.20 - 16.22

Note. Maximum score = 30 * = $p<.05$, significantly different from chance

Table 7

A Repeated Measures ANOVA to Assess Performance on Implicit Learning Tasks

	SS	DF	MS	F	p
Between Subjects					
Within + Residual	913.24	83	11.00		
Alone/Dyad	.97	1	.97	.09	.767
Non-Coor/Coordinator	67.70	1	67.70	6.15	.015
A/D x NC/C	10.24	1	10.24	.93	.338
Within Subjects					
Within + Residual	1040.86	83	12.54		
One and Two Dimension	49.49	1	49.49	3.95	.050
Interaction					
Alone/Dyad X Dimension	4.91	1	4.91	.39	.553
NC/C X Dimension	3.45	1	3.45	.28	.601
A/D X NC/C X Dimension	30.13	1	30.13	2.40	.125

two-dimensional implicit learning task (mean= 15.28) than on the one-dimensional task (mean=16.14). This difference was significant ($F_{1,83}$ = 3.95, p=.050). The dyad by dimension interaction was not significant.

Differences in implicit learning of 1 and 2 dimensional artificial grammars across developmental level - Hypotheses 3a, 3b

The performances of ALONE and DYAD were separated; the performances of coordinators (C) and noncoordinators (NC) on one and two dimensional IL tasks were assessed in each dyad condition. Contrasts (a priori) were run on the data to assess the performances of participants on 1 and 2 dimensional implicit learning tasks. The results are summarized on Table 8.

In the ALONE condition, the noncoordinators (mean = 16.06) and coordinators (mean = 16.42) performed (t_{81}=-.31, p=.760) similarly on the one dimensional IL task. On the two-dimensional IL task, the mean performance for coordinators (mean = 16.00) was higher than the performance of noncoordinators (mean = 14.76), but this difference was not significant.

The performance of the DYAD groups was combined, so noncoordinators who worked with noncoordinators (NC-NC) were combined with noncoordinators who worked with coordinators (NC-C). The performance of all noncoordinator dyads was measured against coordinators who worked with noncoordinators (NC-C) and coordinators who worked with coordinators (C-C). The coordinators (mean = 17.75) performed better than the noncoordinators (mean = 15.13) on the one dimensional IL task; this difference

Table 8

Planned Comparisons between Means for Numbers of Correct Responses to One and Two Dimensional Implicit Learning Tasks

Comparisons	t	DF	p
ONE			
Alone			
Noncoordinators v Coordinators	-.31	81	.760
Dyads			
Noncoordinators v Coordinators*	-2.279	81	.018
TWO			
Alone			
Noncoordinators v Coordinators	-1.226	81	.224
Dyads			
Noncoordinators v Coordinators*	-.618	81	.542

Note. The differing dyads were combined for this analysis only between the two groups was significant (t_{81}=-2.279, p=.018). However, coordinators performed similarly to noncoordinators on the two dimensional IL task.

Additional analysis in the repeated measure ANOVA shows a significant main effect ($F_{1,83}$=6.15, p=.015) for developmental level; coordinators performed better on both one- and two-dimensional implicit learning tasks, and across dyad/alone than did noncoordinators.

Differences between Dyads and Non Dyad Participants in Implicit Learning of 1 and 2 Dimensional Artificial Grammars - Hypothesis 4

Contrasts (a priori) were run to compare the performances of ALONE and DYAD participants on 1 and 2 dimensional implicit learning tasks. In these contrasts, noncoordinators working alone were compared to noncoordinators working with noncoordinators (NC-NC) and to noncoordinators working with coordinators (NC-C). Coordinators working alone were compared to coordinators working with coordinators (NC-NC) and to coordinators working with noncoordinators (NC-C). Only two contrasts approached significance. The noncoordinators working alone (mean=16.06) performed better than the noncoordinators working with noncoordinators (mean=13.86) on the one dimensional IL task (t_{81}=1.772, p=.087). The coordinators working with coordinators (18.42) performed better than the coordinators working alone (16.42) on the one dimensional IL task (t_{81}=1.67, p=.10).

Differences between Non Dyad and Dyad Groups in Grammatically-true Articulations about the Nature of 1 and 2 Dimensional Artificial Grammars - Hypothesis 5a

The analyses performed on the children's articulations were partitions of maximum likelihood ratio chi squares. An ANOVA would have not have been robust in the face of the large amount of "no response" to the queries about clues or patterns. Performance was assessed by assigning participants to one of two classes. Participants that gave at least one grammatically-true articulation about the artificial grammar were assigned in one class, and participants that failed to give any correct articulations were assigned into the other.

The proportion of these two classes was analyzed across conditions as contrasts. The results are summarized in Table 9. The only significant differences in true articulations about the nature of the grammar were found between all groups in the two dimensional condition. More specifically, it was found that a higher proportion of coordinators paired with coordinators (36%) were able to articulate true statements about the nature of the artificial grammar. There was also no significant difference between grammatically-true articulations about one-dimensional and two- dimensional artificial grammars.

Differences between Non Dyad and Dyad Groups in Articulations about their own Behavior (behaviorally-true) - Hypothesis 5b

The analyses performed here were also partitions of likelihood ratio chi squares. The results are summarized in Table 11. In the two-dimensional condition, there was a significant difference between dyads and nondyads in behaviorally true articulations. Dyads (10%) were able to tell more, proportionally, about their behavior than were nondyads (0%). There was also a significant difference between types of dyads in articulations while working on the two-dimensional task. Coordinators paired with coordinators (29%) yielded a higher proportion of articulations than any other dyad type. There was no significant difference in behaviorally true articulations concerning one- vs two-dimensional implicit learning tasks.

Table 9

Partitioned Likelihood Chi Squares for Grammatically True Articulations

	Dimension			
Group	One		Two	
	Chi	p	Chi	p
All Groups	4.56	.47	11.53	.04
Dyad v Non Dyad	1.50	.22	.08	.77
Non Dyad				
Noncoordinators v Coordinators	1.40	.24	.74	.38
Types of Dyads	1.65	.65	10.71	.01

McNemar test for differences in one- and two-dimensional articulations (p=.20)
This difference is not significant.

Note - The df for All Groups = 5, Dyad vs Non Dyad = 1, Non Dyad = 1, Types of Dyad = 3.

Table 10

Percentage of Participants with Grammatically True Articulations

	Dimension	
Group	One	Two
Alone	13 (5/39)	10 (4/39)
Noncoordinators	06 (1/17)	6 (1/17)
Coordinators	18 (4/22)	14 (3/22)
Dyads	23 (11/48)	13 (6/48)
Noncoordinators paired with		
Coordinators	10 (1/10)	0
Noncoordinators	21 (3/14)	07 (1/14)
Coordinators paired with		
Coordinators	29 (4/14)	36 (5/14)
Noncoordinators	30 (3/10)	0
TOTAL	18 (16/87)	11 (10/87)

Note: Percentage = $\frac{\text{participants with one or more objectively true statements}}{\text{total participants in condition}}$

Table 11

Partitioned Likelihood Chi Squares for Behaviorally True Articulations

	Dimension			
Group	One		Two	
	Chi	p	Chi	p
All Groups	8.74	.12	15.01	.01
Dyad v Non Dyad	2.20	.13	6.19	.01
Non Dyad				
Noncoordinators v Coordinators	1.41	.21	0	1.0
Types of Dyads	5.14	.16	8.82	.03

McNemar test for differences in one- and two-dimensional articulations (p=.73)
This difference is not significant.

Note - The df for All Groups = 5, Dyad vs Non Dyad = 1, Non Dyad = 1, Types of Dyad = 3.

Table 12

Percentage of Participants with Behaviorally True Articulations

Group	Dimension One	 Two
Alone	13 (5/39)	0
Noncoordinators	06 (1/17)	0
Coordinators	18 (4/22)	0
Dyads	04 (2/48)	10 (5/48)
Noncoordinators paired with		
Coordinators	0	0
Noncoordinators	0	0
Coordinators paired with		
Coordinators	14 (2/14)	29 (4/14)
Noncoordinators	0	10 (1/10)
TOTAL	08 (7/87)	06 (5/87)

Note: Percentage = $\frac{\text{participants with one or more behaviorally true statement}}{\text{total participants in condition}}$.

DISCUSSION

In the interest of clarity, the discussion will organize results and interpretation of these results by hypothesis. An integration of the results will follow, and the discussion will close with implications for further research in the development of implicit learning.

Pretest- Matrix Completion Task

The matrix completion task was created in order to better delineate developmental level by evaluating the ability of participants to solve and explicitly explain tasks that require coordination of multiple attributes. A measure was needed that more closely connected cognitive developmental change and the ability to demonstrate one and two dimensional implicit learning. This measure would allow for a separation of those who could demonstrate coordination of multiple attributes and those who could not. It was hoped that this cut would represent explicit developmental change and prove a more exact division of implicit developmental change than the relatively arbitrary division of children into different age groups.

The results suggest that the pretest was an effective measure of developmental change in the ability to coordinate two dimensions explicitly. As seen in Table 13, there are significant relationships between explicit cognition as measured in the pretest and one dimensional implicit learning. There is also a significant relationship between pretest scores and the ages of the participants. Does the pretest demonstrate qualitative change? Results show that the criteria chosen to divide the sample into coordinators and non

Table 13

Correlation Matrix for Pretest, Age, and One- and Two-Dimensional Implicit Learning Performance

	Pretest	OneDim	TwoDim	Age
Pretest	——	.278**	.151	.561**
OneDim	——	——	-.041	.218*
TwoDim	——	——	——	-.087
Age	——	——	——	——

** = $p < .001$

* = $p < .05$

coordinators did achieve a significant difference in ages across group, and in the expected direction. Noncoordinators were significantly younger than were coordinators. The bimodal distribution of scores on the pretest, and the significant difference in ages between noncoordinators and coordinators indicate that the possible beginning of the ability to coordinate two or more dimensions in explicit cognition occurs between 6 and 8 years. The observed age difference (6 years 9 months vs. 7 years 11 months) confirms Inhelder and Piaget's.(1964) data on multiplicative classification; Inhelder and Piaget's results also indicate a rise in the ability to coordinate two or more attributes between the ages of 6 years and 9 years.

Implicit Learning of One and Two Dimensional Artificial Grammars

Results support Hypothesis 1a, that there is implicit learning of one dimensional artificial grammars in children, independent of age and development. They do not support Hypothesis 1b, that there is implicit learning of two dimensional artificial grammars in children. Hypothesis 2 posits a significant difference between one- and two-dimensional implicit learning within individuals. Results of the repeated measures ANOVA support this hypothesis.

For the one-dimensional implicit learning task, the mean performance of the entire sample of participants is significantly greater than chance. For the two-dimensional task, the mean performance approaches a significant level of difference from chance, but does not exceed it. On the face of it, such findings may indicate that two-dimensional artificial grammars are not appropriate measures of implicit learning. In other studies of implicit learning, this would be the extent of analysis. However, if participants are implicitly learning the artificial grammar underlying the distribution of symbols in artificial grammar experiments, then we would expect that their performances on one- and two-dimensional implicit learning tasks to be similar.

According to present theories of representation of implicit knowledge, there should be no difference in implicit learning of one dimensional and two dimensional artificial grammars. .If one follows the abstractive view of implicit learning (Reber, 1969; Mathews, et al., 1989; Reber & Lewis, 1977), that participants in implicit learning experiments learn rule-like representations of exemplars which allow them to solve these tasks, then children should be able to process one dimensional artificial grammars as well as two dimensional grammars. The underlying rule structures for one and two dimensional tasks are the same in this study, so abstracted rule structures should also be the same, leading to similar performance. The fragmentary (Servan-Schreiber & Anderson, 1990; Perruchet & Pacteau, 1990) and distributive (Brooks and Vokey, 1991) views would similarly predict no differences in implicit learning of one dimensional and two dimensional artificial grammars; patterns of covariance of symbols in the fragmentary view are the same in the one and two dimensional tasks. The isometric translation of stimulus materials posited in the distributive view also occur similarly in one- and two-dimensional tasks. Finally, the strong evidence of positive transfer between implicit learning of artificial grammars that share the same underlying rule structure, despite changes in the surface structure of the stimulus environment (Reber, 1969;

Howard and Ballas, 1982; Mathews et al., 1989) provide empirical evidence for these theories of representation in adults.

For adults, prior research (Lewis, 1992) indicates implicit learning of two-dimensional artificial grammars, as well as no difference in implicit learning of one dimensional and two dimensional artificial grammars. The data in this study suggest, when children are examined with both one and two dimensional artificial grammars, that differences in implicit learning are apparent. Children in this study do not implicitly learn two-dimensional artificial grammars; children also exhibit significant differences in their performance on one-dimensional versus two dimensional implicit learning tasks. Because of the these differences in adult and child implicit learning, I posit development of the ability to implicitly learn two-dimensional artificial grammar. The issues of development of implicit learning are addressed in the next section.

One and Two Dimensional Implicit Learning across Developmental Level

Hypothesis 3a stated that there is no significant difference in the ability to demonstrate one dimensional implicit learning across developmental level when participants are working alone. This hypothesis is not disconfirmed by the data; there is no significant difference in the ability to demonstrate one dimensional implicit learning across developmental level when participants are working alone. Hypothesis 3b stated that there is a significant difference in the ability to demonstrate two dimensional implicit learning across developmental level when participants are working alone. This hypothesis is not supported by the data.

The performance of noncoordinators versus coordinators in the repeated measures ANOVA demonstrates a main effect for developmental level. Coordinators do significantly better than noncoordinators at the implicit learning of one dimensional artificial grammars. These results would seem to point to a quantitative, not a qualitative change in implicit learning in children as they grow older. Children would demonstrate more knowledge of both one and two dimensional artificial grammars as they grow from noncoordinators to coordinators. But it must be recalled that the sample of children in this study does not demonstrate implicit learning of two dimensional artificial grammars. Because implicit learning of two dimensional artificial grammars is found in adults, but not in children (Lewis, 1992). one would posit the development of this ability to occur after the ages sampled in this study. The development of two dimensional implicit learning would be a qualitative change. However, this leaves the significant difference in performance on two dimensional implicit learning between the two groups in this study, neither of which demonstrates two dimensional implicit learning. A recent study by Maybery, Taylor, and O'Brien-Malone (1995) may shed some light on issues of development raised here.

Maybery, Taylor, and O'Brien-Malone (1995) demonstrate age related differences in implicit learning using a covariation task adapted from Lewicki (1986). This covariation task requires participants to integrate two qualitatively different dimensions in order to show implicit learning. Participants were required to guess the location of a target stimulus in one of four quadrants of a matrix. The location of the target stimulus was determined by both the color (blue or red) of the apparatus surrounding the matrix, and by the direction of approach of the experimenter in presenting the matrix (left or right of the participant). Children between 5 and 7 1/2 years were not able to integrate these two dimensions, while children between 10 1/2 and 12 years were able to show integration. The younger children were determined to have used only one dimension in making their choice. These results are consonant with the results obtained in this study. All of the children in this study are younger than Maybery's older group. I believe that the children in this sample are still too young to successfully demonstrate two dimensional implicit learning of artificial grammars.

One question arises from our examination thus far. It concerns the relationship between explicit cognition as measured by the pretest, and two dimensional implicit learning. Why are coordinators, who are able to coordinate two dimensions explicitly, unable to coordinate two dimensions implicitly? Examination of Table 13, the correlation matrix, shows that there are significant relationships between performance on the one-dimensional implicit learning task and the pretest, between one-dimensional task and age, and between the pretest and age. The two-dimensional task is not correlated with any other variable. It is possible that the pretest and one-dimensional implicit learning share similar developmental trajectories that fall substantially within the age range measured in this study. Two-dimensional implicit learning's trajectory, from data gathered here and in the Maybery study, may fall outside of this age range. This could result in no correlation between performance on the two-dimensional task and age. If the developmental trajectories are truly different, then this finding would also strengthen the case for qualitative differences between demonstration of one- and two-dimensional implicit learning.

There is a conflict between the main effect for developmental level found in the repeated measure ANOVA and the contrasts performed on noncoordinators and coordinators working alone. The contrasts performed on noncoordinators and coordinators do not find significant differences in one- and two-dimensional implicit learning when participants are working alone. The significant difference is found when coordinators and noncoordinators are working in dyads; the performance of coordinators is significantly better than the performance of noncoordinators when working in dyads on one-dimensional artificial grammars. This effect of peer interaction, which is not a part of the effect of peer interaction hypothesized in this study, is examined at the end of the following section.

This lack of significant differences in one- and two-dimensional implicit learning when participants are working alone weakens the argument for development of implicit learning in this study. But the data from the Maybery study, as well as the demonstration of adult two-dimensional implicit learning from Lewis (1992) show that between approximately 10 years and adulthood, children do develop the ability to demonstrate two-dimensional implicit learning. A one sentence answer to the question of implicit learning development from this data would be: Though this study did not unambiguously demonstrate development in children working alone, it did show that the issue of development warrants additional research using children between 10 years and adulthood and two-dimensional implicit learning tasks.

Surface Structure of Artificial Grammars does Matter

This study suggests clear differences in ability to show implicit learning of one- and two-dimensional artificial grammars. These differences may be due to differing representations of artificial grammars. Yet the deep structure (the relation of elements determined by the artificial grammar itself) and the relative frequency of each of the symbols in one- and two-dimensional implicit learning tasks remain the same. In other studies (Mathews, et al., 1989; Reber, 1969) positive transfer, a savings in the amount of time needed to implicitly learn an artificial grammar, was found when participants transferred from one implicit learning task to another task in which the artificial grammar was held constant, but the surface structure (the appearance of the symbols) of the task was changed. For example, an artificial grammar that used the symbols "X","Y", and "Z" in one task might change the symbols to "A", "B", and "C" in the second task, with the underlying grammar remaining the same. In these studies, the prior representation (whatever it was) helped speed the process of implicit learning. When the underlying grammar was changed, but the same symbols were held constant, there was considerable negative transfer. It took longer for participants to learn the new grammar. In this study, the surface structure changes from one dimension of color to two dimensions of color and shape. Since the deep structure of the artificial grammar remains the same, we would expect similar results. Why is difference observed?

The difference may hinge on the interpretation of the problem task by the participant. Interpretation of the one-dimensional implicit learning task is of many differently colored squares while the two-dimensional task is of different colors and different shapes. To maintain that interpretation requires children to hold two dimensions simultaneously and they cannot do so, according to Inhelder and Piaget, until 8 or 9 years. For adults, this interpretation does not cause a drop in implicit learning of two-dimensional artificial grammars because adults have this ability to coordinate two dimensions at once.

Why does interpretation enter into this discussion? Because a computer simulation, confronted with 4 different symbols, would manipulate those symbols without imbuing them with meaning. Those symbols could be colored squares, animal shapes, numbers, letters or different colored shapes; the computer would process all of these symbols in the same fashion. In the implicit learning literature, it was thought that humans also would process all symbols equally. I submit that the processing of two-dimensional artificial grammars is different, that this difference is caused by an error, and that error is an error of meaning and interpretation that the participants bring into their implicit analysis of the artificial grammar.

Cantor (1980) demonstrated that adults who attempted an artificial grammar implicit learning task that featured numbers as symbols were unable to show implicit learning. One possible explanation for this inability may be that adult participants interpreted a string of number symbols not as 3 or 4 or 5 separate number symbols, but as one 3 or 4 or 5 digit number symbol. Thus "53554" was interpreted as fifty-three thousand, five hundred and fifty-four rather than 5-3-5-5-4. Subsequent representation may not have led to implicit learning of the number symbols within the string but as learning of some other system. Participants may have given the number strings a meaning that was erroneous.

If interpretation has an effect on implicit learning, then it is certain that other factors that may affect interpretation of an implicit learning task may affect learning. Some of these factors may be prior training and the learning context. One participant in my prior study of implicit learning, during his debriefing, was able to perform better (93% accuracy) and explain many more of the "rules" of the artificial grammar he was presented with than any other participant I had encountered. He presented the rules as contingencies such as "First you start with a red then you move to a yellow or green. From green to either green or yellow." These contingencies moved as through a flowchart; the finite state diagrams which constitute the artificial grammar appear much like flowcharts. His academic training was as a Ph.D. candidate in computer science, and part of his training, as he explained to me was to design programs (rule systems) o generate output.

Cultural factors may also manifest, perhaps in less decontextualized implicit learning paradigms. One example of one such decontextualized paradigm is the control of complex systems paradigm (Berry, 1994), in which participants must control the production of stimulated sugar factories or city transport systems through manipulation of variables on a computer. The relationship between the variables that control production is a complex set of rules much like an artificial grammar. Participants are traditionally unable to describe this relationship, even as they become proficient at their manipulation (Broadbent, 1977; Berry and Broadbent, 1984; Broadbent, FitzGerald and

Broadbent, 1986). As an example, subcultures of computer-literate gamers may demonstrate different levels of competency than noncomputer-literate musicians at these types of tasks. No research has addressed this question of prior knowledge or skills on implicit learning.

A valid response may be that, all things considered equal, one could expect humans to perform similarly on such tasks. By controlling for such variation, one eliminates the noise caused by variation like prior skills. Another response might be that a decontextualized implicit learning task like the artificial grammar experiment in this study might tap constituent processes that all humans may use in different ways. For implicit learning, the assumption has been that the cognitive mechanisms underlying implicit learning are basic, default modules. The question of interpretation may undermine that assumption.

Peer Social Interaction

Hypothesis 4 stated that there are significant differences between children working alone and children working with a peer in their ability to demonstrate implicit learning of one and two dimensional grammars. This hypothesis focuses on noncoordinators working alone against noncoordinators working together in a dyad; however, all possible dyad combinations were created and assessed against the appropriate group of participants working alone. No significant differences were found between children working alone and children working in dyads in either one or two dimensional implicit learning.

If dyadic interaction has similar effects on implicit learning as it does on the explicit acquisition of knowledge, then implicit learning should be increased in dyad interaction. During the course of data collection, it was observed that interaction within dyads, for *all* dyads, was not based on the goals expected by the experimenter. It was expected that dyads would be concerned with mutual construction of a choice of string which would satisfy the question asked by the experimenter, "Which of these rows is like the rows that you copied?" The verbal interaction observed in virtually all of the dyads seemed to concern the question of who will answer the question about the test card. A sample interaction between two noncoordinators follows:

A: "I think its TOP." [a 7 year, 2 month girl]
B: "I think its BOTTOM." [a 6 year 11 month girl]
A: "You picked last time!"
B: "Noooo!"
A: "Yes, say what I say" [A grabs B's arm]
B: "OK."
A: "OK?"
B: "OK."
A: "TOP!" B: "BOTTOM!"

Both girls burst into giggles.

This subtle difference between expected interaction and observed interaction may have occurred because the children did not understand the procedure, or were bored, or did not want to interact in the fashion expected by the experimenter. But one of these two children, when asked what they were supposed to do, was able to explain that her group was to work together. More importantly, she, as did many other participants, expressed frustration because she did not know which of the two test strings was the correct one. It seems that the nature of the implicit learning paradigm may be a primary cause of the difference between expected and observed interaction.

Implicit learning is in part defined as learning without conscious awareness of one's knowledge. Peer interaction in children involves the expression and justification of their points of view, and the decentration that results from experiencing the expression of another's point of view. But what happens if the child does not have a point of view, or does not know it? If children have little access to knowledge of what they have learned implicitly, then it seems they cannot interact meaningfully with peers over the nature of the artificial grammar. Peer interaction research in the Vygotskian tradition emphasizes the concept of intersubjectivity. As defined by Rommetviet (1985, pg. 187), intersubjectivity comes about as "some aspect of [the problem space] is brought into focus by one participant and [is] jointly attended by both of them." Children in an interaction cannot believe that they are attending to the same aspect of the problem when they are consciously unaware of the extent or even the existence of their knowledge. Therefore, the basis for their interaction must then become something other than sharing a focus, or decentrating their cognition in an implicit learning experiment. Not all peer interactions are created equal; in the peer interaction literature, sociocognitive conflict, negotiation, and mutuality are requirements of cognitive advancement (Doise & Mugny, 1984; Ames & Murray, 1982; Bearison, Magzamen, & Filardo, 1986). For many of the children in this study, the basis of their interaction became the structure of the interaction itself, rather than an exchange of information that the children were unaware they possessed. Without conscious awareness of their knowledge, it may be difficult for children to focus their interaction on what is implicitly learned about artificial grammars. It may also be necessary for children to learn how to interact in ways that promote cognitive development, especially in interactions involving implicit knowledge.

Peer interaction did not have a significant effect on implicit learning when comparisons were made between dyads and participants working alone. But there was an effect discovered between developmental level and implicit learning with dyad groups of different composition. Coordinators in dyads performed better on one-dimensional implicit learning tasks than did noncoordinators in dyads. This difference was not found in coordinators and noncoordinators working alone. It appears that peer interaction exacerbates differences between coordinators and noncoordinators in one-dimensional implicit learning. There is not enough information to posit a theoretical reason for this finding, but one possible reason may be that noncoordinators found that peer interaction actively distracted them from implicitly learning one dimensional grammars. Noncoordinators in dyads also performed worse than noncoordinators working alone, although this difference was not significant; the effort of interaction may have taken away attentional resources needed to implicitly learn. Noncoordinators may also have not learned to profit from peer interaction in implicit learning as have coordinators. No difference may have been found for two-dimensional grammars because both noncoordinators and coordinators cannot show implicit learning of two-dimensional grammars; the effect of peer interaction is overwhelmed by the lack of ability to implicitly learn two-dimensional grammars for all participants.

An alternative explanation for the lack of effect from peer social interaction could lie in the function of explicit learning processes. If explicit learning processes developed because these processes better facilitated social interaction, then implicit processes may be relatively impervious to social context effects as compared to explicit processes.

More research is required to systematically assess the focus and development of peer interaction and its effects on implicit learning. More research with children between 10 and adulthood is also necessary, to establish the trajectory of the gains in implicit learning noticed in coordinators working together, as well as establishing a baseline for the possible effects of social interaction of implicit learning of two-dimensional artificial grammars.

Grammatically-true Articulations and Implicit Learning - dyads vs nondyads

According to Hypothesis 5a, one would expect that participants in a dyad, because they are engaging in social interaction centering on the nature of the artificial grammar, to give more articulations indicative of the true nature of the grammar than participants working alone. This hypothesis is not supported by the data.

The percentage of children who responded to the question "Were there are clues that helped you to pick the right answer?" was fairly substantial; 46% of the total sample gave at least one clue for the one-dimensional grammar, and 53% gave at least one clue for the two-dimensional grammar. The percentages drop precipitously when grammaticality is considered; 18% of the total sample gave at least one grammatically-true answer for the one-dimensional grammar, while 11% gave for the two-dimensional grammar. The difference between one- and two-dimensional grammars is not significant. It is clear that not many of the children in this study have explicit knowledge of the rule systems they have constructed.

This explicit knowledge does not increase when participants are placed in a dyad. The data suggest no difference between dyads and non dyad participants in their ability to articulate grammatically-true clues about the artificial grammars they encounter. Of course, the data suggest that participants in this study do not implicitly learn two-dimensional artificial grammars, so we would not expect explicit knowledge of two-dimensional grammars.

There was a significant difference between different compositions of dyad in the ability to give grammatically-true articulations concerning two-dimensional artificial grammars. The coordinator-coordinator dyad group contained a significantly higher proportion of participants with at least one grammatically-true articulation. This increase in explicit knowledge was not accompanied by an increase in implicit learning, as measured by performance on the two-dimensional task. This might be an expected outcome, in light of the discussion of peer interaction from the previous section. Of all of the dyad groups, it might be expected that coordinator-coordinator dyads would interact in a fashion conducive to successful cognition. As a group coordinators are older than noncoordinators. If there is some developmental trajectory for ability to constructively interact with peers, then one would expect that coordinator-coordinator dyads would be the most developed of all the dyad types. However, the lack of increase in implicit learning makes this a potentially contradictory result; more research is necessary to resolve this issue.

Behaviorally-true Articulations and Implicit Learning

Describing one's own behavior is different than describing the nature of the grammar learned. One can be conscious of one's own performance, and not be conscious of whether that performance is accurate or not, within an implicit learning paradigm. Hypothesis 5b stated that participants that work in dyads would be able to describe their own behavior better than participants that work alone. This hypothesis was supported by the data, for two-dimensional implicit learning.

A smaller percentage of the total sample responded with behaviorally-true articulations than with grammatically-true articulations. For the one-dimensional implicit learning task, 8% of the sample gave at least one clue that accurately described their own behavior. For the two-dimensional implicit learning task, 6% of the sample gave at least one clue that accurately described their own behavior. The difference between one- and two-dimensional tasks was not significant.

There was no significant difference between dyad and nondyad participants in one-dimensional implicit learning conditions. There was a significant difference in dyad and nondyad participants in two-dimensional implicit learning conditions; dyads were more successful at describing their own behaviors than were participants working alone.

The question here becomes: why were dyads better at describing their own behavior only in two-dimensional implicit learning tasks? In statistics, one usually posits the existence of an interaction between two or more variables to produce the kind of effect seen here. Perhaps the ease of communicating something about a one-dimensional grammar allows participants in all conditions to speak equally about their own behavior, and the complexity of a two-dimensional grammar allows only the most cognitively developed participants with the additional help of peer interaction to devote resources to answering questions about their own behavior.

As seen in the previous section of grammatically-true articulations, coordinator-coordinator dyads contained a significantly higher proportion of participants with behaviorally-true articulations than did other kinds of dyads. Similar considerations exist here; the question of possible effects of peer interaction development and the lack of correspondence between ability to learn implicitly and the ability to describe one's own actions are the concerns of future research in this area.

Limitations of This Study

The present study is an attempt to expand present theories of implicit learning. However, more testing of the hypotheses and theoretical details presented in this paper is necessary.

Methodologically, there are four major limitations that should be addressed in future research. The first is the lack of direct examination of adult participants in peer interaction, and in repeated measure of one- and two-dimensional implicit learning. If development is represented by differences between child and adult demonstration of implicit learning, the adult form of implicit learning in these areas must be fully examined. The baseline of the adult form must be established.

The second limitation is the lack of examination of children between 10 years and adulthood. The coordination of two dimensions in explicit cognition occurs between 6 and 8 years, but in hindsight, there seems to be no reason to expect implicit processing to occur in the same age range. Further research must pinpoint the period of development.

The third limitation is in the area of peer interactions. There may not have been peer interaction in the sense that other researchers in the field use the term. Because children often could not interact as if they were focused on the implicit task, we do not know what the true effects of peer interaction are. Because of the inability of children to focus on the implicit learning task, one might question the appropriateness of the task for peer interactions. The artificial grammar task, with its nonrepresentational shapes and color, may not provide a rich domain for discussion in a peer interaction. Other research paradigms, such as the control-of-complex-systems design, could enhance discussion between peers.

Adults must also be assessed in peer interactions. If adults have the same difficulty in interaction while using alternative research paradigms, then it might strengthen the argument that implicit learning is not conducive to peer interaction. There may also be some effect of peer interaction in adult ability to articulate information about their implicit knowledge.

The last methodological limitation lies in the criterion level established for learning the artificial grammar for children. Children may not be able to reach adult ability to learn implicitly two-dimensional grammars not because they are incapable in principle, but because they were not given enough time to learn. Twenty-seven exposures to the artificial grammar may not have given the children in this study enough of a knowledge base to show implicit learning of two dimensional grammars. Additional research is necessary to determine whether more exposure would result in two-dimensional implicit learning in children. I would like to close this discussion with implications for implicit learning research and recommendations for future research into developmental and social aspects of implicit learning.

Implications for implicit learning research

Two findings of the present study with implications for implicit learning research are as follows. First, there is a significant difference between one- and two-dimensional implicit learning in children 5-10 years of age. Second, coordinators are significantly better at implicit learning than non-coordinators. Given present theory as reflected in literature on implicit learning, these findings are not anticipated. Significant differences in one- and two-dimensional implicit learning are indicative of an inability of children between 5-10 years to process implicitly two dimensional artificial grammars under the conditions found in this study.

Present theory (Hayes & Broadbent, 1988; Reber, 1992; Roter, 1985) expects relative age independence from variation in implicit learning; in part, this is expected because of phylogenetic considerations of the hierarchical nature of evolution of implicit learning discussed earlier (Reber, 1992). Differences in coordinators and noncoordinators in implicit learning, and the inability of children to process two dimensional artificial grammars implicitly, as well as other investigations into implicit learning (Maybery, Taylor, & O'Brien-Malone, 1995) place this expectation in question. The inability for children to process two dimensional artificial grammars implicitly, when contrasted with adult ability to process the same (Lewis, 1992) lead one to challenge relative age independence in implicit learning.

Finally, one must question whether implicit learning should be thought of as a unitary cognitive phenomenon or as a family of cognitive processes with different developmental trajectories. If implicit learning is thought of as a set of cognitive processes, then there may be hierarchical phylogenetic development of explicit processes from implicit learning processes. However, some aspects of implicit learning such as one-dimensional implicit learning may occur early in ontogenetic development while other aspects such as two-dimensional implicit learning may develop over the course of childhood.

Implications of Social Context for Implicit Learning Research

The social context of peer interactions has no significant effect on implicit learning. But peer interaction does have an effect on the ability to describe one's own behavior. While peer interaction effects were not significant, the effect of the interaction seemed to emphasize developmental differences in implicit learning. Not enough is known yet about why peer interaction has this effect. Is it that interactions take more attentional resources from younger noncoordinators than from coordinators? There is certainly enough data (Cleeremans, 1993) on the necessity for attention in implicit learning. But why do coordinators' performances remain unaffected or even enhanced by peer interaction? It may be that coordinators were able to take advantage of another child's perspective in order to face contradictions in their own (implicit) cognition, but a more controlled procedure is necessary to answer these questions. The difficulties that children had in peer interactions in this study make implications based on these results premature.

Peer interaction effects on articulation also seem ambiguous. Coordinators benefit from interaction in describing their own behavior. Without replicating these results, and establishing a baseline in later childhood and adulthood, this study can only be seen as a pilot for future research into peer interaction and implicit learning.

Implications of Development for Implicit Learning Research

This study, as stated before, did not show in its results unambiguous support for development of implicit learning. But in combination with data from other studies, it does present developmental differences that have not been found in implicit learning to date. But what exactly is developing when one discusses the development of implicit learning? Is it the development of implicit learning as a separate cognitive system being measured, with one-dimensional implicit learning developing first, and two-dimensional implicit learning following between 10 years and adulthood? Or is there development of some general learning mechanism? Do different kinds of information afford, in the Gibsonian sense, implicit and explicit knowledge, rather than products of different processes in the knowing subject? By calling into question the lack of development and invariance of social and cultural factors, I hope this study begins the expansion and modification of implicit learning from an interesting but specialized faculty within cognition to a more powerful, general, primary cognitive function.

Appendix A

Pretest Script

1. Engage child in small talk to relax. Introduce the child to all the adults working on study.

2. Then say to the child "**We** [experimenter and research assistant] **are studying how children learn and think. We are working with children all over the country. Some of them are younger than you and some of them are older. We would like to ask you some questions and give you some puzzles to work on. Would you like to help us?**" [Yes -go to 3; No- Thank the child and return to classroom]

3. "**Great! Thank you very much. I want to remember that if you don't want to do this anymore, at any time, to tell one of us. You don't have to do it, and we will take you back to your class with no problem, OK?**" [Say with a smile]

4. Test for color blindness and knowledge of shapes. "**Now I'm going to ask you some easy questions.**" [Take out a blue triangle, red circle, yellow square, and a blue circle] "**Show me a blue triangle. Show me a yellowsquare. Show me a red circle. Show me a blue square.**" [After child realizes there is no blue square] "**I was just testing you; you did a great job!**"

5. Ask child to spell name, age, birthday.

6. Start matrix task. "**Here are some puzzles. I'm going to show you a card like this, with one space empty.**" [Show matrix card] "**I'm going to put these four pieces on the bottom.**" [place pieces on bottom of card] "**One of these four pieces goes in this spot.**" [point to empty space] "**Which one do you think goeshere?**" [if child does not place piece, then tell] "**OK, you can put it there.**" Correct answer - "**Could you tell me why you put that piece there?**" After child tells, ask - " **Any other reason?**" If the child gives an incorrect answer then "**If I were going to pick a piece, I would have picked this one. I would have picked it because the triangles go here,** [point to triangle pieces] **and the squares go here.** [point to blue square and correct piece in empty space]. **The yellowsgo here** [point to yellows], **and the blues go here.**" [point to blue triangle and correct piece in empty space]

7. When child understands procedure, move to next card

8. When the child is ready for Matrix 4, then tell child that "**you can use all of the pieces for the rest of the cards.**"

9. When the child is finished with all ten matrices, tell the child that he/she did a great job.

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