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Author(s): Philip David Zelazo and Douglas Frye
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Cognitive Complexity and Control: II. The Development of Executive Function in Childhood

Philip David Zelazo and Douglas Frye[1]

Department of Psychology, University of Toronto, Toronto, Ontario, Canada (P.D.Z.), and Graduate School of Education, University of Pennsylvania, Philadelphia, Pennsylvania (D.F.)

To adults, children's behavior sometimes seems surprisingly perverse. Consider Piaget's (1937/1954) well-known description of his 9-month-old daughter, Lucienne, as they played a form of hide-and-seek. Piaget hid a doll under a cloth (Location A) and Lucienne found it. However, when Piaget very conspicuously hid the doll under a different cloth a mere 10 cm away (Location B), Lucienne insisted on searching at the original location. This persistent (or *perseverative*) error, referred to as the A-not-B error, resembles other errors that are characteristic of children at different ages. Three-year-olds, for example, are unlikely to make the A-not-B error, but they do respond perseveratively on a more complicated task called the dimensional-change card sort (see Fig. 1).

In the dimensional-change card sort, children are shown two target cards, each of which is affixed to a sorting tray. They are asked to sort a series of test cards, each of which matches one target card on one dimension and the other target card on another dimension, into the trays according to one of the dimensions (e.g., for color, they are told, "Put the blue ones here; put the red ones there."). Then, after sorting several cards, they are told to stop playing the first game and switch to another game (e.g., to sort by shape, for which they are told, "Put the flowers here; put the cars there."). Regardless of which dimension is presented first, 3-year-olds typically continue to sort the cards by that dimension despite being told the new rules on every trial and despite having sorted cards by the second dimension on other occasions (e.g., Frye, Zelazo, & Palfai, 1995).

To adults, the A-not-B error and errors on the dimensional-change card sort seem perverse because children appear to act erroneously despite knowing what to do. For this reason, however, these errors

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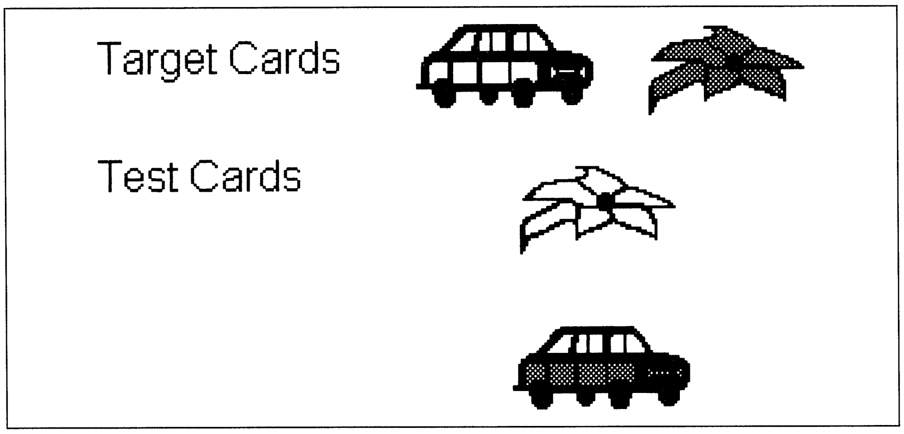

Fig. 1. Stimuli from the dimensional-change card sort, in which children are first told to match test cards to target cards on one dimension (e.g., color) and then told to match the test cards according to a second dimension (e.g., shape).

and others like them provide an opportunity to investigate how it is that children eventually do use their knowledge successfully to control their behavior in these situations. That is, these errors allow researchers to investigate the development of executive function in childhood.

THE FUNCTION OF EXECUTIVE FUNCTION

Like all functions, executive function is properly defined in terms of its eventual outcome, which, in this case, is deliberate problem solving. The various subfunctions of problem solving, from initially representing a problem (i.e., describing the problem to oneself) to eventually evaluating the adequacy of an attempted solution, all contribute to this outcome (see Fig. 2; Zelazo, Carter, Reznick, & Frye, 1997). Research on executive function is aimed at determining the psychological processes that are involved in each of the subfunctions. For example, when searching for a hidden toy or sorting cards on the basis of verbal instructions, children need to represent a problem, select a plan for action, execute the plan (which involves holding a goal or rule in mind and actually acting in light of it), and then evaluate the outcome. But how are these phases of problem solving accomplished? What are the roles played by basic cognitive processes such as memory, inhibition, and awareness?

By determining the exact circumstances in which children at different ages are susceptible to perseveration, and designing tasks that allow us to discover more precisely when in the process of problem solving performance breaks down, we have sought to chart the development of executive function and reveal the way in which basic cognitive processes are normally orchestrated in order to fulfill the higher order function of problem solving. The results of our research have led us to conclude that this orchestration is made possible in part by age-related changes in awareness and in the complexity of children's plans.

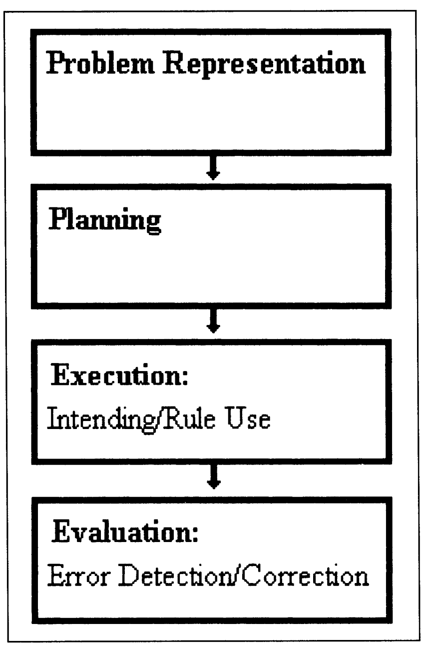

Fig. 2. A problem-solving framework that identifies four temporally distinct phases of executive function.

THE COGNITIVE COMPLEXITY AND CONTROL THEORY

According to the cognitive complexity and control (CCC) theory, there are a number of major developmental transitions in the degree to which children can consciously reflect on their plans. Children's plans are necessarily conditional because one never just acts, one acts when certain conditions are in place (Zelazo & Jacques, 1996). Moreover, their plans are assumed to correspond literally to rules, in potentially silent self-directed speech, linking antecedent conditions to consequences. (Such self-directed speech is also used by adults, as when a person tells himself, "If I see a mailbox, then I need to mail this letter.") When children acquire the ability to reflect on the rules they represent, they become able to consider them in contradistinction to other rules and embed them under higher order rules, in the same way that someone might say, "If it is before 5 p.m., then if I see a mailbox, then I need to mail this letter (otherwise, I'll have to go directly to the post office)." In this example, a simple conditional statement regarding the mailbox is made dependent on the satisfaction of yet another condition, referred to as a *setting* condition (namely, the time).

The tree structure in Figure 3 illustrates the way in which one rule

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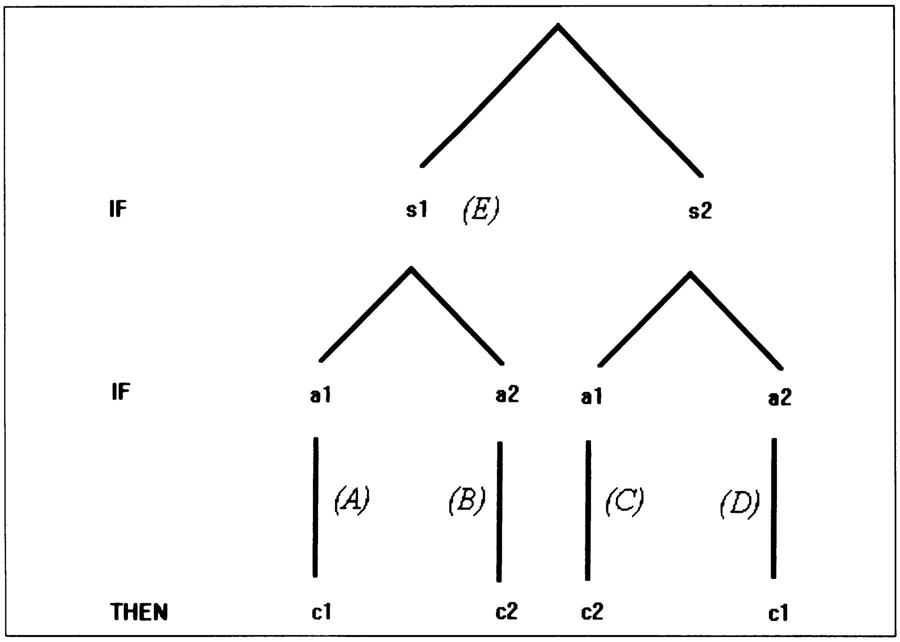

Fig. 3. Hierarchical tree structure depicting formal relations among rules (A–E). Note: s_1 and s_2 = setting conditions; a_1 and a_2 = antecedent conditions; c_1 and c_2 = consequences. The higher order rule (E) requires children to consider both a setting condition and an antecedent condition in order to determine the appropriate consequence.

can be embedded under another and controlled by it. A rule such as A, which indicates that Consequent 1 (c_1) should follow Antecedent 1 (a_1) is incompatible with Rule C, which connects a_1 to a different consequent (c_2). Rule A is embedded under, and controlled by, a higher order rule (Rule E) that can be used to select Rules A and B, as opposed to Rules C and D. In order to deliberate between Rules C and D, on the one hand, and Rules A and B, on the other, children need to be aware of the fact that they know both pairs of rules. Thus, increases in self-reflection on lower order rules are logically required in order for increases in embedding to occur. These increases in embedding provide a metric for measuring the degree of complexity of the entire rule system that needs to be kept in mind to perform particular tasks.

In terms of the dimensional-change card sort (Fig. 1), Rule A might be, "If it's red, put it here," and Rule B might be, "If blue, . . . there." To sort by color, children need to reflect on Rule A and contrast it with Rule B. According to the CCC theory, 2-year-olds represent only a single rule at a time (e.g., "If red, . . . here"). By 3 years, children can easily consider a pair of rules simultaneously ("If red, . . . here; if blue, . . . there"). However, it is not until 5 years of age that children typically represent a higher order rule (such as E) that allows them to select between two incompatible pairs of rules. They can then apply these rules to the stimuli in the dimensional-change card sort as follows: "If we're playing color, then if red car, . . . here, and if blue flower, . . . there, but if we're playing shape, then if red car, . . . there, and if blue flower, . . . here."

For each developmental transition, a general process is recapitulated. Specifically, a conscious rule at a particular level of complexity is acquired, and this rule permits children to exercise a new degree of control over their environment and behavior. However, the use of this rule is subject to limitations that cannot be overcome until yet another level of complexity is achieved.

THREE-YEAR-OLDS' PERFORMANCE ON THE DIMENSIONAL-CHANGE CARD SORT

The limitations, and their implications for the development of executive function, can be seen in a wide range of situations, but they are perhaps best illustrated by 3-year-olds' performance on the dimensional-change card sort. In one study (Zelazo, Frye, & Rapus, 1996), we asked 3-year-olds who had been sorting by one dimension to switch and start sorting by the other dimension. As usual, the majority of children continued to sort by the first dimension.

We then asked these children questions to determine whether they understood what they were supposed to be doing. For example, we asked children who were supposed to be sorting by shape, "Where do the cars go in the shape game? And where do the flowers go?" Almost invariably, children answered these knowledge questions correctly, pointing to the correct tray. Nonetheless, when we then told the children to go ahead and sort the cards according to these rules ("Okay, good, now play the shape game: Where does this flower go?"), nearly all of them perseverated, sorting by color. The children answered an explicit question about the new rules, showing that they knew these rules, but then they immediately persisted in using the old ones.

According to the CCC theory, these kinds of abulic dissociations—that is, dissociations between having knowledge and actually using that knowledge—occur until incompatible pieces of knowledge are integrated into a single rule system via their subordination to a new higher order structure. Three-year-olds know the first pair of rules, and they know the second pair of rules, but they have difficulty "stepping back" from their knowledge and reflecting on the rule pairs and their relation (Zelazo & Frye, 1997). As a result, the pair that they select is determined by relatively narrow considerations, such as the way in which the question is asked or the way in which they have approached the situation in the past.

THE ROLE OF INHIBITION

Another possible explanation of 3-year-olds' perseveration in this situation is that 3-year-olds have difficulty inhibiting prepotent responses because of the immaturity of a mechanism for suppressing behavior (i.e., an inhibition mechanism). Certainly, there is behavioral evidence that young children frequently fail to inhibit their responses (e.g., Dempster, 1992; Diamond & Gilbert, 1989; Harnishfeger & Bjorklund, 1993), but the psychological processes producing these failures remain to be determined.

Several findings suggest that 3-year-olds' characteristic perseverative errors cannot always be attributed to difficulty inhibiting responses per se. One suggestive finding is that 3-year-olds perseverate in the dimensional-change card sort even after a single preswitch trial (Zelazo et al., 1996, Experiment 2). In other words, sorting a card even once by one dimension prevents the majority of 3-year-olds from switching to the other dimension, so perseveration in this situation cannot be due to failure to inhibit a well-practiced response.

Another finding (Marcovitch, Zelazo, Boseovski, & Cohen, 1997) leads to the same conclusion in a slightly different way: Three-year-olds do not seem to "lock in" on a single way of responding to a specific test card. When the dimensional-change card sort was simplified so that children were required to use only one pair of rules but still needed to change the way they responded to a particular card, 3-year-olds effectively inhibited their old way of responding. In this study, children were shown target cards that differed on only one dimension (e.g., a blue rabbit and a red rabbit). They were then presented with a test card that could be matched to either target (e.g., a blue-and-red-striped rabbit), and they were told to use one rule for sorting (e.g., "If we're playing the red game, then put it here"). After several trials, they were told to switch and use a different, incompatible rule (e.g., "If we're playing the blue game, then put it there"). The finding that 3-year-olds switched their responses demonstrates that perseveration is at least partly a function of complexity and is not tied to specific responses or specific stimuli.

A recent set of observations (Jacques, Zelazo, Kirkham, & Semcesen, in press) makes this last point more strongly. Instead of having to sort cards themselves on the dimensional-change card sort, children were asked to evaluate the sorting of a puppet. Thus, the requirement to execute a response was removed from the task altogether. When 3-year-olds watched the puppet perseverate, they judged the puppet to be correct. When they saw the puppet sort correctly, they judged the puppet to be wrong. Moreover, children's judgments of the puppet's performance were highly correlated with their own performance on the dimensional-change card sort.

These results show that 3-year-olds have difficulty formulating what should be done, not just difficulty doing it (cf. Frye, Zelazo, Brooks, & Samuels, 1996; Zelazo, Reznick, & Pinon, 1995). In one sense, the results help us to state more precisely just what it is that 3-year-olds have difficulty inhibiting in the standard dimensional-change card sort: They appear to have difficulty inhibiting the selection of the first pair of rules. However, the results also suggest that these failures of inhibition might ultimately be explained by something other than the failure of a putative inhibition mechanism, such as limitations on memory or reflection. What is needed is a theory of executive function that explains why children at different ages fail to inhibit in some situations and not others.

COMPLEXITY VERSUS CAPACITY

Memory limitations can be considered either in terms of complexity or in terms of capacity, the sheer number of things that must be maintained in memory (Halford, 1993). If 3-year-olds can use a single pair of rules but cannot switch between two different pairs of rules, perhaps this is because a total of four rules exceeds the capacity of their working memory (Case, 1985; Olson, 1993). To test this hypothesis, we asked children to match test cards to four target cards according to four separate criteria (two shapes and two colors). Thus, we used the same number of rules as in the standard dimensional-change card sort, but the rules did not have the embedding that makes the required rule system so complex. For example, we showed children four target cards, a blue rabbit, a red boat, a green flower, and a yellow car, and then asked them to sort test cards showing a red rabbit, a blue boat, a yellow flower, and a green car according to the rules, "If red, . . . here; if blue, . . . there; if flower, . . . here; if car, . . . there."

Contrary to what would be expected if perseveration resulted from capacity limitations alone, 3-year-olds performed remarkably well. What seems to be difficult is arranging the rules into a hierarchy so that one rule can be used to select another rule, which is then applied to a particular situation. According to the CCC theory, 3-year-olds cannot handle these complex, embedded rule systems because they lack the requisite degree of self-reflection.

RELATION BETWEEN EXECUTIVE FUNCTION AND CONCEPTUAL FLEXIBILITY

Using a higher order rule to select another rule can be viewed as choosing how to conceptualize a single situation. In the dimensional-change card sort, children have to conceptualize a test card first in terms of its shape and then in terms of its color, or vice versa. Although 3-year-olds are capable of either conceptualization, they have difficulty switching flexibly between them.

This description of the difficulty that 3-year-olds have on the dimensional-change card sort helps to clarify what is asserted by the CCC theory. What these children fail to do is distance themselves sufficiently from a particular way of conceptualizing a card so that they can select the right conceptualization when the time comes (cf. DeLoache, 1993). Just as physical distance provides a panorama, psychological distance allows children to put each perspective into a larger context.

Children's reasoning about false beliefs, as well as their understanding of misleading appearances (e.g., what something appears to be vs. what it really is; Flavell, Flavell, & Green, 1983), provides an interesting test of this account. The theory predicts that children's understanding of conflicting situations—say, a sponge that looks like a rock—would be related to their performance on tasks assessing executive function. And indeed, this is exactly what a growing number of researchers have found (e.g., Bialystok, in press; Carlson, Moses, & Hix, 1998; Frye et al., 1995; Hughes, 1998; Moore et al., 1995; Ozonoff, Pennington, & Rogers, 1991; Perner, Stummer, & Lang, in press).

As Luria (e.g., 1961) noted in his seminal work on the subject, key aspects of cognitive development can be described in terms of the growth of executive function. Characteristic age-related changes in executive function are evident across a wide range of cognitive tasks. By conceptualizing executive function according to the problem-solving framework, it has been possible to ask more precisely which aspects of executive function are vulnerable to inflexibility in which situations. The results of our research indicate that the likelihood of executive errors resulting in perseveration depends in part on an interaction between the age of the child and the complexity of the rule systems that are required for success on particular tasks. In the end, consideration of the role of complexity in executive function has led us away from observing the execution of errors themselves and toward an account of how performance depends on the level of reflection at which children conceptualize their own ability to solve a problem.

Note

1. Address correspondence to either P.D. Zelazo, Department of Psychology, University of Toronto, Toronto, Ontario, Canada, M5S 3G3, or D. Frye, Graduate School of Education, University of Pennsylvania, 3700 Walnut St., Philadelphia, PA 19104; e-mail: zelazo@psych.utoronto.ca or doug@psych.nyu.edu.

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Teaching-Centered Schooling Has Reached Its Upper Limit: It Doesn't Get Any Better Than This

Robert K. Branson[1]

Center for Performance Technology, Florida State University, Tallahassee, Florida

Teaching as we know it—to classes in rooms in schools—predates scientific knowledge about learning and intellectual development. Because early teaching processes could not be based on valid principles of learning and intelligence, they relied mainly on philosophical and oral-tradition rituals. Learning was not studied empirically until the 1870s in Wundt's laboratory, long after the traditional model was in place. The situation of education today is much like that of medicine before Semmelweis discovered sepsis and Pasteur discovered microorganisms.

In applied science, valid knowledge flows from the laboratory into practice, and there is continuous interaction between the field and the laboratory. This knowledge sharing does not now happen in education. A heated controversy being debated in the education literature is whether teachers or professors of education should set the research agenda. Yet in the current model, it does not matter who sets the agenda; research-based discoveries are rarely applied consistently, nor are they incrementally improved in many schools.

Current job responsibilities for teachers provide little discretionary time to plan and think. As a consequence, teachers must ignore significant psychological research literatures, including the literatures on assessment, behavior analysis, learning and cognitive development, transfer, simulation, expertise, learner strategies, and industrial and organizational psychology.

Figure 1 presents the traditional model of education, called teaching-centered schooling. In this model, individual teachers develop lesson plans, deliver instruction to classes of students, make the majority of decisions regarding methods and means, and conduct assessments. The success of schools depends totally on individual teachers' abilities to develop valid lessons and to deliver and assess them so that they cause learning in students. Although students can learn in classes, learning is always an individual phenomenon. Classes are artifacts of administration and theater; they have not been derived from the science of learning. The teaching-centered model is unlikely to produce a high proportion of students who are self-initiating, independent, lifelong learners who will thrive in an information society.

In my view, the basic teaching-centered model, used predominantly in American schools, has reached the *upper limit,* or asymptote, of its potential capability (Branson, 1987). Smith (1981) concluded that all technologies follow the same developmental path, and Figure 2 presents a general performance curve modeled after his work. The figure shows that teaching processes approached asymptote around 1960 (see Bracey, 1991, 1997). Because a process cannot ex-

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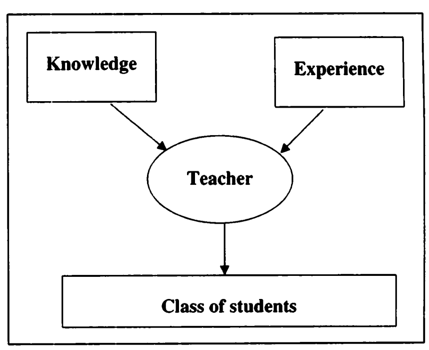

Fig. 1. The teaching-centered model of schooling in the oral tradition.

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