The cognitive consequences of collaborative problem solving with and without feedback

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Abstract:

The goal of this research was to assess the impact of feedback, partner, and shared understanding in the course of problem solving. A sample of 180 6- to 9-year-olds was pretested to discover the children's "rule" for predicting the movement of a mathematical balance beam. For the treatment they either worked alone or with a partner who was equally, less, or more competent, with two-thirds receiving feedback from the materials. They subsequently participated in 2 individual posttests. The results revealed that children receiving feedback improved significantly more than those who did not, but that the presence of a partner was only beneficial when children received no feedback. Irrespective of feedback, those children whose partner exhibited higher-level reasoning were far more likely to benefit from collaboration than those whose partner did not, provided that the pair achieved shared understanding.

Keywords: Reasoning | Adopted children | Collaboration | Cognition | Language development | Problem solving | Children | Social cognition

Article:

A good deal of research, conducted over the past 2 decades, has focused on peer and adult-child collaborative problem solving and its effects on the child's cognitive development (for recent reviews, see Azmitia & Perlmutter, 1989; Chapman & McBride, 1992; Garton, 1992; Tudge &

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Rogoff, 1989; Tudge & Winterhoff, 1993b). Studies have been set within a variety of theoretical perspectives, most notably those of Piaget, Vygotsky, and Bandura. Scholars working in the Piagetian tradition have argued that cognitive growth should occur when children working to solve a problem have different perspectives and engage in sociocognitive conflict (Ames & Murray, 1982; Doise & Mugny, 1984; Murray, 1972, 1982; Perret- Clermont, 1980). Vygotskian scholars inter- ested in the impact of social interaction on cognitive growth have proposed a different mechanism, whereby a more competent social partner provides assistance within a child's "zone of proximal development" in such a way that shared understanding is attained between the partners (Forman, 1987, 1992; Forman & Cazden, 1985; Forman & McPhail, 1993; Tudge, 1992; Wertsch & Hickmann, 1987; Wertsch & Sammarco, 1985). Scholars influenced by Bandura's social learning theory (now termed "social cognitive theory" [Bandura, 1986]) have also examined cognitive change wrought under the influence of a partner. Unlike Piagetian or Vygotskian scholars, however, they argued that imitation of a model, not sociocognitive conflict or arriving at shared understanding, is the primary mechanism inducing change (Rosenthal & Zimmerman, 1972, 1978; Zimmerman & Blom, 1983; Zimmerman & Lanaro, 1974).

The results of studies of peer collaborative problem solving have been far from consistent. Some scholars have documented that such interaction is an effective means of bringing about cognitive growth in young children, particularly when one child is more advanced (Ames & Murray, 1982; Bearison, Magzamen, & Filardo, 1986; Doise, Mugny, & Perret-Clermont, 1975; Light, 1983, 1986; Mackie, 1983; Miller & Brownell, 1975; Murray, 1982, 1983; Perret-Clermont, 1980; Perret-Clermont & Schubauer-Leoni, 1981; Tudge, 1989, 1992; Tudge & Winterhoff, 1993a), and even when partners use incorrect, but different, approaches to reach solutions (Ames & Murray, 1982; Glachan & Light, 1982). However, in some studies children have not improved as a result of collaborative problem solving (Doise & Mugny, 1984; Mugny & Doise, 1978; Perret-Clermont, 1980; Russell, 1982), and in some cases they even have regressed (Levin & Druyan, 1993; Rosenthal & Zimmerman, 1972, 1978; Tudge, 1989, 1992; Tudge & Winterhoff, 1993a; Zimmerman & Lanaro, 1974). The goal of this article is to shed light on the reasons for these discrepant findings, and to examine some of the conditions that are most likely to be conducive to growth.

Three plausible, though not necessarily mutually exclusive, explanations for these discrepancies will be the focus of this article. One has to do with the nature of the pairings. As Tudge (1989) argued, Piagetian studies in which conservers were paired with nonconservers may have increased the likelihood of ensuring progress (and limited the possibility of regression), by virtue of the specific dyadic relationship that this pairing pattern creates. From a Piagetian perspective, conservers are not simply more advanced in their thinking than nonconservers; they are necessarily more certain of their position than are their nonconserving partners (Miller, 1986). This artificial confounding of competence and confidence may have been an important determinant of the pattern of results found by many Piagetian scholars, and may partially explain the inconsistent results found when pairs of nonconservers work together.

Tudge's (1989, 1992) data suggested that when children who were more competent were not necessarily more confident the results were quite varied. Specifically, Tudge demonstrated that children whose rules for predicting the working of a mathematical balance beam did not allow for consistency of prediction were likely to regress when paired with a partner whose rule was less advanced but allowed consistent prediction. By contrast, a similar child, paired with a partner whose rule was more advanced and allowed consistent prediction, was likely to improve. Similarly, Levin and Druyan (1993) found that children who held a common misconception regarding movement and speed were more likely to express their views with confidence than their partners whose position was correct but counterintuitive. The formerly correct partners in this situation were likely to regress in their thinking. Ellis and Siegler (1994) reported a study by Ellis, Siegler, and Klahr (work in progress) in which children who worked with a more competent partner on decimal fraction problems improved far more when their partner was consistently rather than inconsistently correct in his or her responses. The partners who were consistently correct in their responses tended to provide what Ellis and Siegler termed "more convincing arguments" (1994, p. 349).

A second possible explanation is that collaboration is more likely to lead to cognitive growth when the pair members are actively involved in the collaborative process, and when it is a process in which they attain shared understanding. For example, among Piagetian scholars, Bearison and his colleagues found that cognitive growth was most likely to result from a fairly balanced pattern of arguments "in which each partner is able to contribute equally to the social dialectic that structures the coordination of interindividual perspectives" (Bearison et al., 1986, p. 69). Russell (1982) found that improvement was likely only when the target child's partner provided some explanation for his or her more advanced thinking. Similarly, Perret-Clermont and her colleagues argued that the "interpersonal coordination of actions and symbols" (Perret-Clermont, Perret, & Bell, 1991, p. 44) in the course of mutually constructing an understanding of the task was an important factor leading to growth. Light and Glachan (1985) and Mackie (1983) also found that dyads who argued little and were relatively passive were less likely to benefit than those who were more actively engaged in the task. Scholars who have been influenced by Vygotsky have made very similar points-namely, that to understand the consequences of collaboration requires examination of "the process by which children's goals, attitudes, and understandings were established, negotiated, and modified before and during their collaboration" (Forman & McPhail, 1993, p. 225).

A willingness to discuss how to solve problems may be necessary for growth, but it is not sufficient; partners must resolve those different perspectives, and arrive at shared understanding. Tudge (1992) found that when a more advanced partner brought to bear thinking that was at a higher level than that used by the target child, *and* the target child subsequently adopted that reasoning in the course of discussion, improvement in thinking was highly likely to result. Similarly, Forman and McPhail (1993) found that partners were likely to show cognitive growth when they "listened to each other's explanations and reflected on their logical consistency and precision" (p. 224). As Light and Perret-Clermont argued, "pragmatic, intersubjective agreements-in-meaning [lie] at the heart of the developmental process" (1989, p. ll0). In a somewhat different domain, that of moral reasoning, Kruger (1992, 1993; Kruger & Tomasello, 1986) found that development was most likely following "coconstruction" of understanding, a construct that implied working cooperatively to resolve disagreements. Conflict between partners, with no shared resolution, is in general unlikely to aid development.

A third possible explanation that might help us to make sense of the conflicting results of research on peer collaboration is that cognitive growth is more likely to occur under conditions in which children receive clear feedback as to the correctness of their proposed solution. Support for this view can be found in several studies on feedback where social interaction was not a focus. For example, Spiker, Cantor, and Klouda (1985), using multidimensional reasoning tasks, found that a combination of contingent corrective feedback and preliminary training with simple forms of the task resulted in increased performance levels among kindergarten and first-grade children. In studies in which feedback is inherent to the task (i.e., children necessarily see whether their attempts to reach solutions are correct), similar advances in performance have also been found. Welsh (1981) argued that optimal performance on the Tower of Hanoi task was observed when children had access to feedback provided by the materials. This finding was in marked contrast to research that was similar in all respects except the provision of feedback, that is, in studies where children only verbalized their planned move sequences but did not actually carry them out (Klahr & Robinson, 1981).

Feedback per se is not necessarily beneficial, however. If feedback is delayed (i.e., noncontingent), its effects may be less noticeable. In a logo programming task, Johnson and Kelly (1992) found that performance with immediate feedback was better than with delayed. Differences in effects of feedback have also been found to relate to whether access to feedback is temporary or continuous (Ludlow & Woodrum, 1982), and to feedback sequence (Fuchs & Turner, 1981). It is clear, therefore, that the manner in which feedback is presented influences its effects on cognitive development.

Most studies of collaborative problem solving do not distinguish between the effects of feedback and social interaction. When a child works with a partner on a problem such as model copying (Azmitia, 1988; Azmitia & Hesser, 1993; McLane, 1987; Wertsch, 1979; Wertsch & Hickmann, 1987) or the Tower of Hanoi (Glachan & Light, 1982; Light & Glachan, 1985), in which feedback is provided through the task itself, the distinctive effects of feedback and social interaction cannot be identified. The separate effects of feedback *or* social interaction were examined by Freund (1990). Freund found that when 3- to 5-year-olds interacted with their mothers throughout the task, their independent problem solving improved more than that of an equivalent group of children who received explicit feedback at the end of the task, but who had not interacted with their mothers. Freund' s research thus failed to control simultaneously for feedback and interaction.

One of the few groups of researchers who have explicitly examined both social interaction and feedback is Ellis and her colleagues (Ellis, Siegler, & Klahr, work in progress, cited in Ellis & Siegler, 1994). These researchers studied children who worked on mathematical (decimal fraction) problems either alone or with a partner, and either with or without feedback. Ellis and Siegler (1994) reported that children who worked with a partner and who received feedback did better on an individual posttest than singletons who received feedback. Irrespective of partner or singleton status, those who did not receive feedback did not improve.

Recent studies have thus provided discrepant results regarding the effect of peer collaboration on cognitive development. Our research was designed to examine three of the possible reasons for these discrepancies. The goal was to compare children who received feedback from the equipment with those who received no such feedback, either working as singletons or with a partner. Among those who worked with a partner, we wished to compare children whose partner used the same thinking about the problem with those whose partner used discrepant thinking. Our hypotheses were (a) that children who received feedback from the materials would improve more than those who did not, regardless of pairing, and that improvement would be stable across posttests; (b) that children who worked with a partner would improve more than those who worked with no partner, regardless of feedback; (c) that those who worked with a more competent partner (based on pretest scores) would improve more than those whose partners were either less or equally competent, regardless of feedback; and (d) that among those who worked with a partner, growth would be more likely among children who adopted higher-level reasoning in the course of collaboration because their partner exposed them to or supported that reasoning.

Method

Subjects

The sample consisted of 180 children aged 6 to 9 years, of whom six were subsequently dropped because they did not meet the minimum requirements of the study. Of the 174 who participated further, 79 were female (M age = 89.2 months, SD = 8.7, range 72-110 months) and 95 were male (M age = 89.9 months, SD = 8.3, range 79-113 months). Only two of these children were aged 9 and so they were combined with the 8-year-old group, forming three groups, 6-year-olds (n = 45, M = 80.1 months, SD = 2.65), 7-year-olds (n = 89, M = 89.2 months, SD = 3.27), and 8- to 9-year-olds (n = 40, M = 101.3 months, SD = 3.85). Participants were drawn from first- and second-grade classrooms from two open-enrollment public elementary schools, and consisted predominantly of white children from a mix of social classes.

Materials

A mathematical balance beam was used, similar to that used first by Inhelder and Piaget (1958), developed further by Siegler (1976, 1981), and employed by Tudge (1989, 1992; Tudge & Winterhoff, 1993a). We used this task because it allowed us to identify a number of different "rules" that children use to predict the workings of the beam, where each rule requires thinking that deals with the relevant variables in a more sophisticated way than lower rules.

The beam had eight removable sticks placed at equal distances from the central fulcrum, and was held stable by wooden blocks supporting it at both ends. The blocks were removable to allow the children to observe free movement of the beam at the start of the experiment, but thereafter remained in place. Metal nuts that fitted over the sticks were used as the weights in the treatment phase. In the pretest and two posttests the materials were representations of the beam on paper, with the position of the weights clearly marked. The configurations were identical at pretest and second posttest, but different at the treatment and first posttest, so that the children would be less tempted to try to "remember" configurations they had seen in the previous session.

The actual configurations were, with minor variations, those used by Tudge (1992), and consisted of 14 different problem configurations for the pretest and posttests, including four simple distance problems and two each of five other "problem types" (see Fig. 1). The terms "balance," "weight," and "distance" refer to the free movement of the beam (that the beam would balance, tip to the side with the greater number of weights, or tip to the side on which the weights are furthest from the fulcrum), and "complex" refers to the fact that number of weights and distance from the fulcrum vary simultaneously. In each case, the weights were depicted (in the paper-and-pencil component that constituted the pretest and two posttests) or placed (in the treatment session) on only one stick on each side of the fulcrum, with a maximum of six weights on any one side and a maximum of 10 on both sticks.

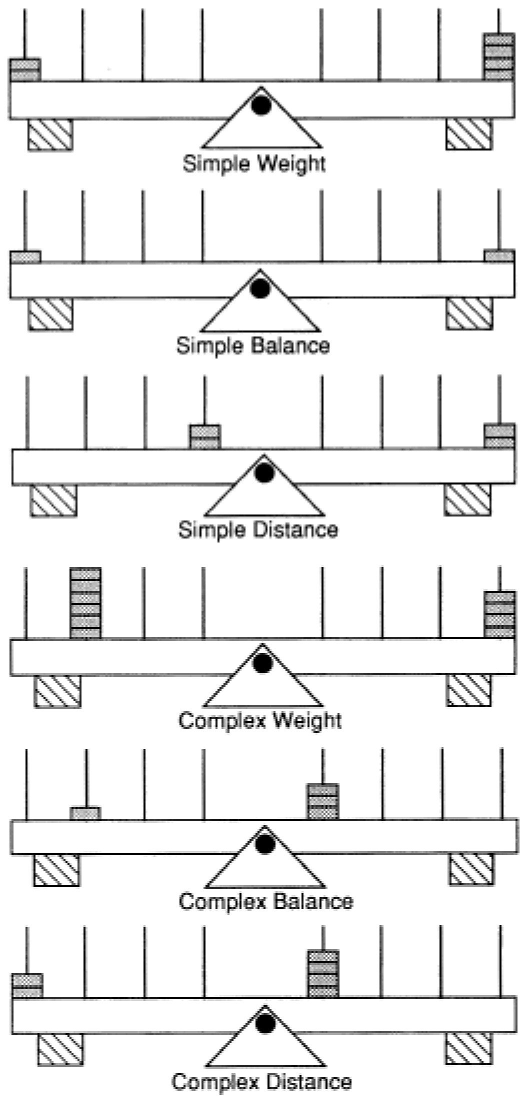

Figure 1. Examples of each of the six types of balance beam problems.

Assignment to Rule

Tudge (1992) identified seven rules that children use to predict the movement of a balance beam when different numbers of weights are placed at varying distances from the fulcrum. The rules range from simple guesswork, with no consistent attempt to consider either number of weights or distances, to the ability to predict precisely what will happen when any configuration of weights is placed on the beam.

Rule 0.—No understanding either of the idea of balance or of what will happen when one side of the beam has more weights. Of the original 180 children who were tested, six were dropped as they used Rule 0.

Rule 1.—Children using this rule consistently predict the side that has the greater number of weights will tip down (simple weight and all complex problems [see Fig. 1]), but inconsistently guess either one side or the other for problems with equal weights (simple balance and distance problems). Six children, mean age 86. 7 months, range 76-105 months, used this rule.

Rule 2.—Children using this rule consistently predict the side that has the greater number of weights will tip, and that the remaining problems will balance. Fifty-eight children, mean age 88.0 months, range 72-105 months, used this rule.

Rule 3.—Children using this rule consistently predict that the side with the greater number of weights will tip, and that the simple balance problems will balance. Their predictions about the four simple distance problems are inconsistent, however; when the difference in distance is great (e.g., one set of weights at the end and the other close to the fulcrum), they are likely to take account of distance, whereas if the difference in distance is small they will not. Thirty-five children, mean age 87.8 months, range 74-105 months, used this rule.

Rule 4.—Children using this rule consistently predict that the side with the greater number of weights will tip, that the simple balance problems will balance, and that the simple distance problems will tip to the side with weights furthest from the fulcrum. Children using this rule simultaneously consider the variables of number and distance when the numbers of weights are equal but the distance is not. Forty children, mean age 92.1 months, range 75-113 months, used this rule.

Rule 5.—Children using this rule predict consistently (and correctly) for all the simple problems, but predict inconsistently for the complex problems. Children using this rule view distance as important even when the numbers of weights are different, but sometimes predict that the complex problems tip to the side with greater number, sometimes to the side with greater distance, and sometimes balance-and make their decision by guesswork. One or more predictions in which a child argued that distance was as or more important than numbers of weights on the complex problems was sufficient to classify that child as using Rule 5, assuming that the remaining predictions were appropriate to Rule 4. Thirty-five children, mean age 92.4 months, range 81-110 months, used this rule.

Rule 6.—This rule features an understanding of what will happen in each problem, gained by multiplying the number of weights by the distance from the fulcrum. All configurations can be consistently and correctly predicted. No children used this rule.

To ascertain which rule children used required examination of the entire pattern of predictions and justifications to all 14 problems. A minimum of 13 of 14 problems was used to classify a child; one prediction, at variance with the remaining pattern, was insufficient to move a child to the next lower rule. However (as mentioned above with respect to Rule 5), one discrepant prediction and appropriate justification was sufficient to move a child to the next higher rule, as this provided evidence that the child had the ability to apply that rule correctly. By contrast, predicting and justifying at a lower level on just one of four similar problems could be attributed to carelessness.

Procedure

Pretest.—The experimenter (a white female) explained and demonstrated the working of the apparatus to all children in the classroom, after which those who had permission to participate in the research were given one of two forms (differing solely by presentation order), on which 14 problems were presented. Each child was asked to mark one of the boxes on the left, right, or center of the beam to indicate his or her prediction that the beam would stay balanced or tip one way or the other given the depiction of weights on the beam. (Three practice problems were given so that the experimenter could be sure that the children knew how to mark the boxes appropriately.)

Treatment.—The treatment phase occurred a minimum of four days (maximum 16 days) after pretesting in each class (M = 7.30 days, SD = 3.23). Singletons and pairs were initially determined on a potential basis, dependent on the number and gender of children in each classroom who had used Rules 2-4 at the time of the pretest. Only children using these rules could qualify as "targets," those who would become the focus of this study (children using Rule 1 could not be paired with a less competent child and those using Rule 5 could not be paired with a more competent child). In addition, pairs had to be of the same gender and could be no more than two rules apart. The goal was to ensure an approximately equal number of singletons, equal rule partners (one target and one partner), less competent target members of a pair, and more competent target members of a pair. All children using one of Rules 2, 3, or 4 were then randomly assigned to fill the slots that had been previously determined. This procedure resulted in 88 target children being in one of four treatment conditions: (1) a group featuring children who were not paired *(n* = 26); (2) a "same rule" group, in which each target child was paired with another child who, at pretest, had used the same rule as the target child *(n* = 18); (3) a "more competent partner" group, in which each target child was paired with another child who, in the pretest, had used a higher rule than the target child *(n* = 24); (4) a "less competent partner" group, in which each target child was paired with another child who, in the pretest, had used a lower rule than the target child *(n* = 20). Subsequently, approximately two-thirds of the children from each group were randomly assigned to receive feedback from the materials.

The particular problems that were provided during the treatment were tailored to the target child; of the eight problems provided, half consisted of those that were solvable by the rule that he or she had used during the pretest and the other half were solvable by the rule that was one higher. For children using Rule 2, therefore, the more difficult problems were simple distance problems in which the differences in distance from the fulcrum were large; children using Rule 3 received four simple distance problems in which the differences in distance were minimal; children using Rule 4 received four of the "complex" problems.

Members of pairs took turns to be the first to predict each configuration. After both had made their predictions, each child was asked, in turn, to justify his or her prediction. When their predictions conflicted, the children were asked to explain their reasons to one another and reach agreement on one prediction. At this point, the experimenter left the room (to allow the children to discuss freely), returning when the children had reached agreement. After agreement had been reached, approximately two-thirds of the children (target $n = 55$) received feedback; that is, the experimenter removed the supports holding the beam in place, so that the children could see whether their prediction was correct. The remaining children (target $n = 33$) received no feedback at any time, either from the materials or from the experimenter.

Posttests.—All children were retested individually, to determine whether or not there had been any change in their rule use several days after the treatment (M = 6.68 days, SD = 1.99, range 5-20 days). A second posttest was given, to determine the stability of any changes that might have taken place, a minimum of 2 weeks after the first posttest (M = 28.0 days, SD = 2.10, range 16-35 days).

The records for the pretest and both posttests were all independently coded by the experimenter and a second coder to ascertain which rule each child used in that session. This was determined by the pattern of predictions for the fourteen configurations. Interrater agreement of assignment to rule was consistently high, 96.6% for the pretest (across all rules and ranging, by pretest rule, from 91.4% to 100%), 93.6% for the first posttest (ranging, by rule, from 80.0% to 95.0%), and 97.0% for the second posttest (ranging, by rule, from 83.3% to 100%). When there were disagreements, the protocols were rescored by both coders (blind as to the earlier score) and discussed until disagreements were resolved.

The treatment sessions were videotaped, and a separate set of coders (blind as to the partners' pretest rules and type of pairing) coded the predictions made by each partner, their justifications following the predictions and during any discussions, and the reasons for any changes of mind during the discussion. Justifications were of four types: no or idiosyncratic justification ("I like the blue side"); considering only number of weights, irrespective of distance from the fulcrum; considering distance, when the number of weights was equal; and considering distance from the fulcrum when the number of weights was unequal. The reason for a child's change of mind could be coded in three main ways: the child appeared to accept the partner's reasoning, the child talked him/herself around without benefit of the partner's reasoning, and the child appeared to go along with the partner without accepting his/her views (perhaps because of a desire to end discussion, perhaps because of perceived inability to sway the partner, perhaps because partners were simply taking turns in accepting the other's opinions). In addition, the children occasionally failed to respond or did so in a way that could not be heard. Excluding this latter category, interrater reliability (computed on 50% of the treatment sessions) for each of these variables exceeded 80% (range 81.2% for reason for change of mind to 98.8% for prediction). Disagreements were discussed until resolved.

Coding the justifications and reasons for change of mind allowed us to determine whether the target children were exposed to higher-level reasoning (i.e., reasoning associated with a higher rule than they had themselves used at the pretest) by their partner and whether or not they subsequently adopted it when trying to solve a similar problem. To code a child as having been exposed to higher-level reasoning, the partner had to predict the movement of the beam in a manner consistent with use of a higher rule and also justify that prediction using reasoning associated with that higher rule. For children to be coded as having adopted higher-level reasoning, they had to clearly predict and justify those predictions using reasoning appropriate to that higher rule. Occasionally children simply gave way to their partner (wanting to go on to the next problem, or deciding it would be futile to try to convince the partner), in which case they were not coded as having adopted that reasoning. All paired sessions were independently coded and high reliabilities were achieved for reasoning exposed to (87.8%), and reasoning adopted (90.9%). All disagreements were discussed until resolved.

The situation was a little more complicated for those receiving feedback. For example, a child using Rule 2 would be likely to argue that the beam would balance with two weights at one end and two near the middle, and her partner might be persuaded. Following feedback, however, the children could see that the beam had, in fact, tipped, and her partner might now explain why. Thus, for those children who received feedback, we coded whether or not they had been exposed to higher-level reasoning prior to receiving feedback on a relevant problem or whether the partner had provided reasoning to explain the feedback only subsequently. Problems that could be solved by the target child's pretest rule (in this example, Rule 2) were irrelevant in this regard-feedback following a simple weight problem would not afford discussion of the role played by distance from the fulcrum.

Because the methodology followed here is similar to that employed by Tudge (1992), it is important to mention points of dissimilarity. First, in this study, but not that of Tudge (1992), some of the children received feedback from the materials. Second, the children who acted as participants in this study were drawn exclusively from first and second grade, rather than kindergarten through fourth grade. (It is worth pointing out that no differences in the patterns of change had been found in Tudge's [1992] study as a function of age.) Third, in this study the pretest and two posttests were conducted as paper-and-pencil tests, whereas in Tudge's (1992) study all sessions involved the physical apparatus. Children as young as 5 years of age had, in an earlier study (Ferretti & Butterfield, 1986), used schematic representations of the beam to make their predictions, and pilot testing by the first author had confirmed that 6- to 7-year-olds were capable of using this simpler and less time-consuming method. Fourth, during the treatment session, the problems to be solved were restricted so as to be solvable by use of a rule just in advance of the target child. The fact that in the earlier study children worked on the full range of problems did not make the problems more difficult for them, for an acceptable solution could be found for all problems using any rule; only with feedback does it become clear that many apparent solutions are in fact incorrect.

Results

Consequences of Collaboration

Initially, we shall focus on the consequences of collaboration (pretest-posttest changes) rather than on what occurred in the treatment or collaborative session (for those who worked with a partner) itself. A 4 (condition: singletons, same rule partners, less competent partners, more competent partners) × 2 (gender) × 3 (age group: 6-yearolds, 7-year-olds, 8- to 9-year-olds) × 2 (feedback; yes, no) × 3 (time: pretest, posttest 1, posttest 2) multivariate analysis of variance (MANOVA) was conducted, using a multivariate approach to the analysis of repeated-measures data (Maxwell & Delaney, 1990). Scores at each time point ranged from Oto 5 (1-5 at the pretest, but children could decline from 1 at either posttest), corresponding to the rule used on each test. The first four factors were between-subjects factors, the fifth within-subjects. The General Linear Model of SAS (SAS, 1989) was used to allow for unequal cell sizes, and an alpha level of .05 was used for all statistical tests. Only target children were used in the analyses, for two reasons. One was that this allowed independence of the units of analysis. A second was that the problems assigned at treatment were designed specifically for the target children. One target child was unavailable for the first posttest, and a further four were unavailable for the second posttest; these children were therefore dropped from all analyses, leaving a total of 83.

The MANOVA revealed that the only significant effects were time, a main effect, and the time × feedback × condition interaction. The data were therefore collapsed across age group and gender, and all subsequent analyses focus only on time, feedback, and condition, and the interactions between them. The results reported here refer to the *independent* effects of each variable, controlling for all others.

The MANOVA revealed that time, as a main effect, was significant (Wilks's lambda $F[2, 74] = 29.32$, $p < .0001$), indicating that the rules used by these subjects changed over time. Across all conditions these children (pretest $M = 2.87$, SD = 0.87) improved by approximately one rule by the time of the first posttest (M = 3.89, SD = 1.10) and by a little more· than three-quarters of a rule by the second posttest (M = 3.64, SD = 1.35). The time x condition interaction was not significant (Wilks's lambda $F[6, 148] = 0.89$, $p > .4$), and while the time × feedback interaction was also not significant, it approached significance ($F[2, 74] = 2.79$, $p < .07$). However the interaction of time × feedback × condition was significant (Wilks's lambda F[6, 148] = 2.71, $p < .05$).

The feedback × time interaction, as mentioned, was not significant; however, the critical question was not whether the effect of feedback was consistent at all times, but when such an effect occurred. The expectation was that this would occur during the treatment session (when some of the children were actually provided feedback) and that changes would therefore occur between the pretest and first posttest, with relative stability between the first and second posttests. To test this, we ran individual univariate tests of contrast to compare scores between the pretest and first posttest and between first and second posttests. The models tested feedback, condition, and the feedback × condition interaction, but the effects reported reveal the effects of each independent of the others.

These analyses revealed that the children who received feedback improved significantly more than those who did not from pretest to first posttest ($F[1, 75] = 5.32$, $p < .05$) but not from first to second posttests ($F[1, 75] = 0.14$, $p > .7$). In other words, the significant changes in rule use for those with feedback took place between the pretest and first posttest, that is, during the treatment session. Children given feedback improved more than twice as much as their counterparts who did not receive feedback, as can be seen in Table 1, clearly supporting our first hypothesis. Condition, as a main effect, was never significant. However, there was a significant condition × feedback interaction when comparing pretest and first posttest ($F[3, 75] = 3.03$, $p < .05$) but not when comparing the first and second posttests ($F[3, 75] = 2.29$, $p < .10$), again indicating that the critical changes occurred during the treatment and that the scores remained stable between posttests. The pretest scores and those at the time of the two posttests are displayed in Table 1.[1]

Table 1. Mean Rule Use at Pretest and at Both Posttests, by Feedback and Pairing

		Pretest		1st Post		2nd Post	
Group	***N***	***M***	**(SD)**	***M***	**(SD)**	***M***	**(SD)**
Feedback:							
Singletons	15	2.87	(.92)	4.67	(.49)	4.73	(.46)
Same rule	12	3.17	(.83)	4.25	(.62)	3.50	(1.45)
More comp. p	14	3.07	(1.00)	4.50	(.94)	4.07	(1.00)
Less comp. p	12	3.33	(.78)	3.92	(.90)	4.17	(.94)
Combined	53	3.09	(.88)	4.36	(.79)	4.15	(1.06)
No feedback:							
Singletons	10	2.30	(.48)	2.50	(.71)	1.80	(.63)
Same rule	6	2.50	(.84)	3.17	(.98)	3.00	(1.26)
More comp. p	7	2.29	(.76)	3.00	(1.15)	2.71	(1.11)
Less comp. p	7	2.86	(.69)	3.86	(1.35)	3.86	(1.35)
Combined	30	2.47	(.68)	3.07	(1.11)	2.73	(1.28)

Note. More comp p. = more competent partner, Less comp p. = less competent partner.

Because the condition × feedback interaction term included three degrees of freedom, further analyses were conducted. Two critical comparisons were necessary, both of which examined those who received feedback and those who did not: First, between singletons and children who worked with a partner, to test the hypothesis that paired children would improve more than singletons; second (for those who worked with a partner), between those whose partner was more competent and those whose partner was not more competent, to test the hypothesis that the former would improve more. To test the first of these hypotheses, groups of paired children were collapsed into one and a 2 (condition: singletons, pairs) × 2 (feedback) × 3 (time) repeated-measures MANOVA was conducted. Time, as a main effect, was significant (Wilks's lambda $F[2, 78] = 26.9, p < .0001$), the time × condition interaction was not significant ($p > .5$), the time × feedback interaction was significant (Wilks's lambda $F[2, 78] = 7.61, p < .005$),[2] and the time × feedback × condition interaction was significant (Wilks's lambda $F[2, 78] = 6.24, p < .005$). As with the earlier model, individual univariate tests of contrast compared scores between the pretest and first posttest and between first and second posttests. As in the earlier analysis, condition was not significant ($p > .7$), but both feedback and the condition × feedback interaction were significant when comparing pretest to first posttest ($ps < .001$). When comparing scores at first and second posttest, neither condition nor feedback were significant, as in the earlier analysis; however, the condition × feedback interaction was significant ($F[1, 79] = 4.73, p < .05$). The analyses revealed that for children who received feedback, singletons (pretest $M = 2.87$, SD = 0.92) significantly outperformed their paired counterparts (pretest $M = 3.18$, SD = 0.87) in

[1] More children were in the feedback than the no-feedback groups, thereby making significant results more difficult to attain for the latter groups. However, children in the no-feedback groups had pretest scores that were approximately half a rule lower than their counterparts who received feedback. In effect, this meant that children without feedback could, potentially at least, improve more than those who received feedback (they were further from ceiling) and could regress less. If feedback had made no difference, children who did not receive feedback would have improved rather more than their counterparts who had received feedback. In fact, they improved less.

[2] The fact that the time × feedback interaction was significant at the $p < .005$ level in this analysis and only approached significance ($p < .07$) in the earlier analysis is simply a result of redistribution of the degrees of freedom when the three paired groups were collapsed into one.

terms of improvement from pretest to first posttest as indicated by rules used at the first posttest (M = 4.67, SD = 0.49; *M* = 4.24, SD = 0.85, respectively; *F*[l, 51] = 5.06) and continued to show a significantly greater degree of improvement at the time of the second posttest (M = 4.73, SD = 0.46; *M* = 3.92, SD = 1.15; respectively; *F*[l, 51] = 7.52, $p < .01$). By contrast, singletons who did not receive feedback (pretest *M* = 2.30, SD = 0.48) only improved slightly by the time of the first posttest (M = 2.50, SD = 0.71), whereas children who were paired (pretest *M* = 2.55, SD = 0.76) improved a good deal more (although not significantly more, as indicated by scores at the first posttest; *M* = 3.35, SD = 1.18; *F*[l, 28] = 2.05, $p < .20$). Unexpectedly, singletons actually declined to below their pretest scores from first to second posttest (M = 1.80, SD = 0.63), whereas paired children did not, only falling slightly from their first posttest scores (M = 3.20, SD = 1.28). This difference in the amount of change from the pretest between singletons and paired children at the second posttest was significant (*F*[l, 28] = 6.01, $p < .05$). These results thus provide only partial support for the second hypothesis. As displayed in Figure 2, only in the no-feedback condition did children who worked with a partner improve more than singletons.

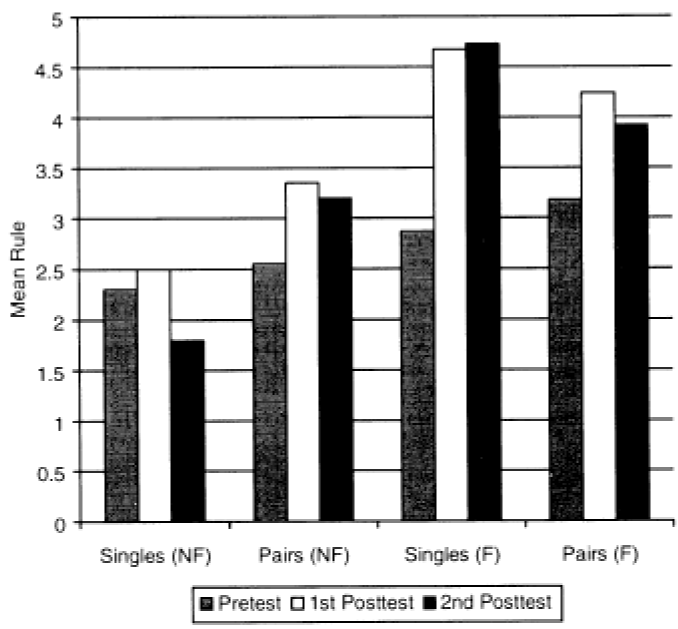

Figure 2. Mean rules used at pretest, first posttest, and second posttest by singletons and pairs with no feedback (NF) and feedback (F).

To test the third hypothesis, singletons were dropped from the analyses, and children who had worked with a more competent partner were compared with the other children. We conducted a 2 (condition: children whose partners were more competent, children whose partners were equally or less competent) × 2 (feedback) × 3 (time) repeated-measures MANOVA. Time, as a main effect, was significant (Wilks's lambda F[2, 51] = 16.0, $p < .0001$), but the time × condition, time × feedback, and time × condition x feedback interactions were not significant (*ps* > .3). The hypothesis that children working with a more competent partner would improve more than other paired children was not supported.

The Collaborative Session

The data presented so far relate solely to the consequences of collaboration, and indicate that receiving feedback seems sufficient to help a child advance in his or her thinking on a problem of this type, although working with a partner may be more helpful than working alone where no feedback is provided. However, as may be seen in Table 1, there is a fair amount of within-group variability. A more fine-grained picture is revealed by examination of what occurred in the collaborative session (for those who worked with a partner), examining separately children whose partners were more competent at the time of the pretest, those whose partners were equally competent, and those whose partners were less competent.

Children whose partners were more competent.—As displayed in Table 2, there were 21 of these children who completed both posttests, of whom 14 received feedback. Examining the seven target children in the *no-feedback* group first, three of them improved at both posttests. Of these three, all had been exposed by their partner to reasoning at a higher level during the collaborative session and had themselves adopted that reasoning during that session. Of the remaining four target children, one declined at both posttests; he had also been exposed to higher-level reasoning by his partner, but had not adopted it. The remaining three children continued to use the same thinking at both posttests. Only one of them had been exposed to higher-level reasoning by her partner; she had adopted it during the collaborative session, but it clearly had no long-term effect on her thinking.

Table 2. Decline, Continued Use of Same Rule, and Improvement, Related to Exposure to and Adoption of Higher-Level Thinking, by No-Feedback and Feedback Groups

	No Feedback					Feedback				
	↓↓	↓	=	↑	↑↑	↓↓	↓	=	↑	↑↑
More competent partner:										
Neither exposed nor adopted	0	0	2	0	0	1	0	0	0	0
Exposed but not adopted	1	0	0	0	0	0	0	0	0	0
Adopted but not exposed	0	0	0	0	0	0	1	0	0	0
Adopted, then supported	—	—	—	—	—	0	0	0	1	4
Exposed and adopted	0	0	1	0	3	0	1	0	0	6
Partner used same rule:										
Neither exposed nor adopted	0	1	1	0	0	0	0	0	0	0
Exposed but not adopted	0	0	1	0	0	0	0	1	0	0
Adopted but not exposed	0	0	0	0	0	0	1	0	0	1
Adopted, then supported	—	—	—	—	—	0	1	0	0	4
Exposed and adopted	0	0	0	2	1	0	1	0	1	2
Less competent partner:										
Neither exposed nor adopted	1	0	0	1	1	2	0	0	0	0
Exposed but not adopted	0	0	0	0	0	0	0	0	0	0
Adopted but not exposed	0	0	0	0	1	1	0	0	0	0
Adopted, then supported	—	—	—	—	—	0	0	0	0	6
Exposed and adopted	0	0	1	0	2	0	0	0	1	2

Note. ↓↓ decline at both posttests; ↓ decline at one posttest (three possible patterns-see below); = continued use of pretest rule at both posttests; ↑ improvement at one posttest (three possible patterns-see below); ↑↑ improvement at both posttests. The three possible patterns subsumed under "↓ decline at one posttest" can be defined using ordered pairs of symbols, the one on the left representing the first posttest and the one on the right representing the second posttest. The symbol "=" stands for "use of pretest rule," "↓" for decline (relative to pretest rule), and "↑" for improvement (relative to pretest rule), and the three patterns are: ↓ =; = ↓; ↑↓. Analogously, the three possible patterns subsumed under "↑ improvement at one posttest" are: ↑ =; = ↑; ↓↑. In cases where changes occur in opposite directions (relative to the pretest) on the two posttests, the change *at the second posttest* is taken to define whether a child was an "improver" or "declined."

Of the 14 target children in the *feedback* group, 10 improved at both posttests. All 10 adopted higher-level reasoning during the collaborative session and either were exposed to that reasoning by their partner prior to relevant feedback or, after feedback, heard their partner use that reasoning. Of the four children who did not consistently improve, one declined at both posttests—she had not been exposed to higher-level reasoning by her partner, and did not adopt it. The remaining three children from this group improved at only one of the posttests. All had adopted higher-level reasoning during the collaborative session, one having been exposed to it prior to feedback, one having worked with a partner who supported higher reasoning following feedback, and one who received no support for that reasoning either prior to or following feedback. One possible reason for the unexpected decline of three of these children, including the child who declined at both posttests, is that their more competent partner had used Rule 5 at the pretest. Children using Rule 5 could employ higher-level reasoning on all complex problems (problems in which distance from the fulcrum and numbers of weights vary simultaneously), but still predict incorrectly. Although we have no direct evidence for this, it is conceivable that target children faced with incorrect predictions might have had less confidence in their partner's ability.[3]

More children in the feedback group adopted higher-level reasoning with the assistance of their partners than was the case for the children who did not receive feedback, but the combination of being exposed to higher-level thinking and coming to adopt it subsequently in the session was a potent stimulus to change in both groups.

Children whose partners used the same rule.—There were 18 such children, of whom 12 received feedback. Of the six target children who were in the no-feedback group, three showed some improvement (two of them only improved at the time of the first posttest, and reverted to their earlier rule at the second posttest). Each of these children had been exposed to higher-level reasoning by their partner during their collaboration, and had adopted that reasoning. Of the remaining three children, two continued to use the same rule, and one declined (although only at the first posttest). Only one of these children had been exposed to higher-level reasoning by the partner, but had not adopted it.

Of the 12 target children in the feedback group, only four failed to improve, only one of whom had been exposed to higher-level reasoning and had adopted it prior to feedback. Of the remaining three, two adopted higher-level reasoning under the influence of the feedback, but in only one case did the partner support that reasoning, and the effects did not carry over to the posttests. The remaining child in this group was exposed to higher reasoning by her partner, but did not herself adopt it, continuing to use reasoning appropriate to her pretest rule. By contrast, of the remaining eight children in this group, all but one improved at both posttests (one

[3] It is worth emphasizing that in four other cases in which Rule 4 users were paired with a partner using Rule 5, improvement at both posttests resulted from collaboration; as these Rule 5 children were equally likely to predict incorrectly, it is difficult to argue that this fact in itself led their partners to lack confidence in their opinions. In principle, on complex weight problems (in which the beam tipped to the side with greater numbers of weights, despite being closer to the fulcrum), Rule 5 users could predict incorrectly even while using more advanced reasoning than lower rule children who predicted accurately simply by taking number of weights into account. In fact, this never happened.

improved at only one posttest), all of whom had adopted higher-level reasoning during the collaborative session, and all of whose partners had either exposed them to that reasoning prior to relevant feedback or supported that reasoning following feedback.

As was true for the children whose partners were more competent, the exposure to higher-level reasoning and subsequent adoption of it during the session were likely to lead to cognitive growth. Not surprisingly, this was more likely to occur for those who received feedback (and thus independent confirmation of the more advanced thinking), but was also true for half the children who received no feedback. A similar situation was found for those children whose partners were less competent than they were.

Children whose partners were less competent.—This group consisted of 19 children, of whom 12 received feedback. Of the seven children in the no-feedback group, four improved at both posttests. Three of them had adopted higher-level reasoning during the collaborative session, two of whom had been exposed to it by their partner. The other had neither been exposed to nor adopted it, and it is not clear what accounted for his improvement at both posttests. Of the remaining three children, one declined at both posttests (not having been exposed to or adopted higher-level reasoning), one continued to use the same rule at both posttests (despite having been exposed to higher-level reasoning and having adopted it during the collaborative session), and one improved at the first posttest only (not having been exposed to or adopted higher-level reasoning during the collaborative session).

Of the 12 children in the feedback group, eight improved at both posttests. Of the four who did not, one improved only at the time of the second posttest, and three actually declined at both posttests. Although these three children received feedback from the materials, their partners did not provide supporting reasoning, and in two of the cases the target children simply adopted the reasoning of their less competent partners. Of the eight children who showed consistent improvement, all were either exposed to higher-level reasoning prior to relevant feedback or had partners who supported that reasoning after feedback.

The impact of reaching shared understanding.—Pairs in which the target child was either exposed to and adopted higher-level reasoning or whose partner supported that reasoning following feedback may be said to have arrived at shared understanding at a level more sophisticated than that shown by the target child at pretest. Reaching shared understanding in the collaborative session was highly effective in ensuring advancement in thinking by the target children. To show its effectiveness, we contrasted improvers and nonimprovers (for criteria see Note to Table 2) by whether the pairs had or had not attained shared understanding. The relation was tested by Fisher's Exact Test (two-tailed), and was found to be significant, different both for those who did not receive feedback ($N = 20$) and for those who received feedback ($N = 38$) ($ps < .05$ and $< .001$, respectively). These data thus support the fourth hypothesis and indicate that improvement was above all likely when the target children adopted higher-level reasoning in the course of collaboration, either because they were exposed to that reasoning by their partner or, in the case of those who received feedback, because their partner provided such reasoning in support of the feedback.

Discussion

The literature on peer collaborative problem solving has revealed quite discrepant results. This study was undertaken to understand better the impact of working as a singleton or with a partner of greater, lesser, or the same competence either with or without feedback from the materials. Some of the results were as hypothesized. First, children who received feedback from the balance beam improved significantly more than those who did not. This finding is consistent with research on feedback; this type of contingent feedback, geared to provide assistance at and somewhat above the level of each target child, has often been effective. Second, these data provide some support for previous research into the effects of peer collaboration; as hypothesized, children who worked with a partner did somewhat better than those who had no partner, but only under conditions of no feedback. By contrast, and contrary to our hypothesis, for those receiving feedback, working with a partner was actually less effective than working as a singleton, a finding that conflicts with that reported by Ellis and Siegler (1994). Third, and also contrary to our hypothesis, children who worked with a more competent partner did not improve significantly more than those whose partner was equally or less competent, particularly under conditions of no feedback. This finding runs counter to much of the prior research on the effects of peer collaboration, including research using a very similar methodology, albeit without provision of feedback (Tudge, 1992). Fourth, as hypothesized, cognitive growth was far more likely for those children who were exposed to higher-level reasoning (or whose partner supported it, following feedback) during the collaborative session itself and who adopted that reasoning during the session. Although proportionally more children arrived at shared understanding in the feedback group (because, following feedback, they had the opportunity to reflect jointly on what they saw happen), when it occurred under conditions of no feedback, cognitive growth was as likely to occur.

One reason for the relatively high (compared to Tudge, 1992) rate at which children improved in the no-feedback condition may be the fact that in this study the problems were tailored to the target child in each pair, the most difficult being solvable by use of a rule one above that which the target child used at the pretest. There was no such limitation in Tudge's 1992 study. There are both theoretical and empirical grounds for limiting the problem difficulty in such a way that the material to be learned is not far in advance of the learner. Both Piaget and Vygotsky made this claim. Piaget (1985/1975) argued that a certain amount of discrepancy with the child's current cognitive structures provided the disequilibrium, and resulting "optimizing equilibration" so critical to development. A "conflictual situation ... is not perturbing in some absolute way but is perturbing in proportion to the degree to which the structure being formed has already been acquired" (Piaget, 1985/1975, p. 33). Among those influenced by Piaget, Kuhn (1972) first made the strongest case for this position, indicating that there was an optimal mismatch between the child's current ability and the problem to be solved, and other scholars have provided supportive data (Mackie, 1983; Mugny & Doise, 1978; Perret-Clermont & Schubauer-Leoni, 1981). Vygotsky's concept of the zone of proximal development is also built on the notion of cognitive proximity-that development is most likely when the problem on which a child is working (with the help of a more competent partner) is not too far in advance of his or her current level of thinking (Vygotsky, 1987). In this study we did not test the impact of varying both feedback and problem difficulty, and so cannot judge whether children improve more or less when the difference between the child's initial level of understanding and the understanding needed to solve the problems is more than the minimum that was a feature of this study.

The fact that the target children were working on problems somewhat in advance of their current level of cognitive development does not explain these findings in their entirety, of course, for not all children improved. Some continued to use the same rule throughout and some regressed in their thinking and did not return to their earlier level of thinking even by the second posttest. Receipt of feedback clearly helped, but even that was not sufficient to ensure cognitive growth.

Invoking the role played by the partner cannot aid understanding of the fact that singletons, with feedback, improved more than those children who worked with a partner. Although this was not investigated, a plausible interpretation is that simply working with a partner is not at all the same as collaborating to solve a problem. The cognitive benefits of peer collaboration are generally interpreted in terms of the opportunity it affords for coming to grips with alternative perspectives and co-constructing a more sophisticated level of understanding. Another possible effect of collaborative situations, however, is that they afford opportunities for social interaction that are not related to the task-partners may actually distract each other from working to solve the problem. This might explain why singletons were often successful; for them there was no possibility of assistance, but also no possible distraction. When provided with feedback, singletons simply tried to make sense of it, and often were successful. However, without the assistance provided by feedback, and with no possibility of help from a partner, the majority continued to use the same rule, and some declined by the time of the second posttest.

Another issue relates to the confidence with which children express their views. As mentioned above, Tudge (1989) argued that the pattern of results reported by Piagetian scholars might be in part a function of the fact that competence and confidence were confounded. In this and a subsequent paper (Tudge, 1992), he indicated that the nature of the rules themselves helped to explain the pattern of improvement and regression that he reported. He noted that three of the rules (Rules 1, 3, and 5) necessarily involve some inconsistency in prediction (whereas Rules 2, 4, and 6 allow consistent prediction), and found that children using these rules were more likely to improve when partnered by a child using a higher, consistent rule and to regress when that partner used a lower, but consistent rule. Our focus in this study was solely on target children who had used Rules 2, 3, and 4, and children using Rule 3 (involving some inconsistency of prediction) could be contrasted with those using either Rule 2 or Rule 4. For those not receiving feedback, the situation was somewhat comparable with the results reported by Tudge (1992). For example, of the 10 singletons who did not receive feedback, the only children who regressed at either posttest were those who used Rule 3, whereas none of those who used Rules 2 or 4 did so. Similarly, of the target children who worked with a less competent partner, the only one who declined had used Rule 3. However, a further three Rule 3 children who worked with a less competent partner actually improved, a finding at variance with that reported by Tudge (1992). The explanation for this discrepancy is that in these cases the child's partner provided supportive reasoning. For children receiving feedback, the situation was quite different; paired children using Rule 3 were as likely to improve as paired children using Rules 2 or 4, collapsed (Fisher's Exact Test, $N = 38$, $ps > .3$ at both posttests), and no singletons regressed. This is hardly surprising, of course; children whose rule incorporates some uncertainty and who receive no feedback and no assistance from their partner might be expected to fall back to a lower rule that allows confident prediction of all problems, whereas those who initially were equally unsure of their position but who receive help understanding a rule that is both more sophisticated and allows confident prediction might be expected to improve.

The issues discussed here (presence or absence of a partner, provision or nonprovision of feedback, the relative distance in rule use, exposure to and acceptance of higher-level reasoning, and partner confidence) should not be considered as conceptually distinct, even though they have been discussed separately. For example, children who did not consider or who were uncertain about the role played by distance from the fulcrum could be helped in a number of ways, some of which clearly interrelate. They could benefit from feedback alone, by seeing that their predictions on some problems were incorrect. For feedback to be effective, however, each child had to reach understanding of why the beam tipped as it did. Without feedback, there was no basis on which to re-evaluate predictions that were, unknown to them, incorrect. A more competent partner could assist, even without feedback, if he or she were able and willing to do what feedback could do nonverbally—namely, offer a verbal argument about the role played by distance. However, just as a singleton who receives feedback may not be able to reach understanding of why the beam behaves as it does, a paired child may not accept a more competent partner's reasoning, particularly in the absence of feedback. Not surprisingly, a more competent partner is more likely to have his or her reasoning accepted if it is supported by feedback, and that feedback is most likely to be effective if the partner can verbalize his or her explanation of the beam's behavior. A more competent partner is more likely to provide such explicit reasoning if he or she is sure of that reasoning. Arriving at shared understanding may even be thought of as a form of feedback (suggesting that both partners are correct), although a form that is likely to prove less beneficial than shared understanding reached after feedback provided by the materials themselves.

Alternative explanations have been raised for some of the discrepancies in previous findings that were not addressed in this study. For example, some scholars have argued that older children may be more likely to benefit from collaboration than those who are of preschool age (Azmitia & Perlmutter, 1989; Tudge & Rogoff, 1989), and data provided by a number of scholars (Azmitia, 1988; Cooper, 1980; Koester & Bueche, 1980; Tudge & Winterhoff, 1993a) support that viewpoint. Each of these scholars argued that young children rarely discussed the problems they were trying to solve. In this study, however, the children are of an age at which discussion is much more likely.

Some of the inconsistency in previous findings might be related to the differing theoretical perspectives that scholars have brought to bear on this problem-some of the early research conducted by Piagetian scholars might have artificially increased the likelihood of cognitive advance by creating pairs in which the less competent children were also the less confident of their opinions. Similarly, the apparent regressions reported by scholars working within the social learning framework may have been only temporary, brought about by children bowing to the social pressure of having an adult provide incorrect responses. Nonetheless, studies conducted over the past few years and set within both the Piagetian and Vygotskian frameworks have yielded a wealth of data that provide a more consistent set of conclusions. These are conclusions, moreover, that might help teachers who are interested in encouraging pair (or group) work within their classrooms.

First, simply pairing children, even if they bring different perspectives to bear on the task, will not necessarily lead to cognitive advance. It is more likely to do so if the problem to be solved is potentially "within reach" of the children, but what is within reach may be determined by a number of factors. One factor is that of problem difficulty, for example, when the problem to be solved is only a little above the children's current level. A second factor relates to the ease with which the teacher can provide feedback, either from the materials themselves or (although this was not assessed in this study) personally. A third factor is that of partner ability; teachers will make progress more likely by providing children with partners who are more competent, so that they can help with problem solution or explain feedback once it is provided. These requirements satisfy the Vygotskian conditions of providing information within the child's zone of proximal development, but also are not alien to Piagetian views of sociocognitive conflict that is created by somewhat discrepant information or perspective on a task (Kuhn, 1972; Mackie, 1983; Mugny & Doise, 1978).

A second conclusion is that providing problems that are potentially within a child's zone or incorporate an optimal mismatch may be necessary but not sufficient for aiding development. It would also be helpful for teachers to encourage children to share the goal of collaborating to reach a solution, offering their ideas on how that solution is to be reached, discussing those ideas, trying to understand the task a little better. In this study, the children who arrived at shared, and higher, understanding in the collaborative session were those who were most likely to continue to exhibit that higher level of understanding in the two posttests. By contrast, children who either were never exposed to higher-level reasoning by their partners, or who were, but did not adopt that reasoning during the collaborative session, were far less likely to improve, even with feedback.

Finally, teachers should be aware that although having children work together may prove beneficial there are also limitations. Having a partner is not simply a source of assistance to a child; it can also prove a distraction, perhaps removing attention from the feedback provided by the problem. These data suggest, in fact, that if problems are proximal to the child's current level of understanding, and he or she is given contingent feedback, cognitive development may occur without a partner's assistance. However, in the absence of feedback, having a partner (particularly one who is more competent) is more beneficial than working alone.

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