

Children's performance on and understanding of the Balance Scale problem: the effects of parental support

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Abstract

Efforts to integrate accounts of scaffolding with Karmiloff-Smith's (1992) RR model have produced renewed interest in the language that tutors use to guide activity, since this provides a mechanism by which redescription of learners' representations might be achieved. The present research examined the impact of two forms of parental input, explicit operationalisations of strategies and explanations of principles, on changes in children's performance and understanding across a series of Balance Scale problems. Children aged 6 to 8 years worked on these at three time-points, receiving assistance at the first. Relative to controls who received no assistance on these problems, these children showed more rapid gains in the accuracy of attempted solutions, and were unique in exhibiting improvement in explicit understanding. Gains of both types were most pronounced amongst children whose parents focused on verbalising the weight x distance computations necessary to solve the problems, and on providing explanations of the underlying principle at work. These children showed earlier integration between performance and understanding, and made earlier use of such explanations themselves, the frequency with which they did so being directly related to parental use. The study provides clear evidence that appropriation of tutors' language may be a significant mechanism in representational change, but it also indicates that initial representational level may constrain children's capacity to benefit from this.

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According to Vygotsky (1978), higher psychological processes originate in children's internalisation of sign operations, which they use to control their actions. These operations are first acquired whilst undertaking a joint activity, working with a more able individual within the child's zone of proximal development. The more able individual uses sign operations, typically in the form of language, to guide the child's actions, and with this guidance the child is able to complete activities that s/he could not accomplish alone. The child then appropriates these operations and uses them to direct his or her own actions, first externally (often in the form of what Piaget, 1952, termed egocentric speech) and then internally.

This characterisation of the process of development emphasises two key elements, an external to internal shift in control, and a central role for symbolic or linguistic mediation in achieving this shift. Various contemporary theorists have tried to specify the nature of this process in more detail, but have tended to focus on the former at the expense of the latter. Bruner and Wood's elaboration of the concept of scaffolding in the context of problem-solving activity (Wood, Bruner and Ross, 1976), for instance, concentrates on the deployment of assistance by tutors, arguing that this varies as a function of both the individual concerned and the moment to moment performance of the child. Thus Wood and Middleton (1975) found that tutors (in this case, parents) differed in their ability to promote children's learning. Those who proved successful, though, exhibited assistance that was contingent in the sense that they only intervened when the child faltered, and then at the least intrusive level of control needed to move performance forward (e.g. using general verbal prompts if these were sufficient, rather than specific verbal instructions or direct interventions;

see Wood, 1986). Sign operations remain implicitly involved in this process, but it is the contingent nature of interventions that is emphasised, this being seen as promoting appropriation and self-direction on the part of the child.

Rogoff's (1990) account of guided participation focuses more on task-related intersubjectivity than precisely definable regulatory sequences. The role of language is central here, partly in terms of its role in negotiating a "meeting of minds" (Garton and Pratt, 2001) about the nature of the task and how to proceed. In addition though, as adult and child work through a task together, it is claimed that their "dialogic exchange" (Fernyhough, 1996) becomes internalised by the child and facilitates his or her ability to employ similar strategies on subsequent occasions. In this way, s/he shifts from being a recipient of adult regulation to self-regulation (cf. Baker and Brown, 1984; Wertsch, 1977). It is control that remains focal in this account, however, and what is absent is any very precise consideration of what language *content* might be involved in this process, and what impact it might have.

There are in fact few empirical studies that focus systematically on the impact of external assistance on children's learning in terms of the relations between the content of linguistic exchange and children's progress. Indeed, much research has tended to focus on whether external assistance leads to positive outcomes, and the factors that might affect those outcomes (e.g., Baker, Sonnenschein and Gilat, 1996; Conner, Knight and Cross, 1997; Kermani and Brenner, 2001; McNaughton and Leyland, 1990), rather than on the process of learning or the mechanisms involved (cf. Chen and Siegler, 2000). Where process-oriented research has been conducted, it is characteristically qualitative in nature, and focused on specific exchanges rather than attempting to extract more general principles across a range of cases (e.g. Gonzalez, 1996). In addition, there are almost no studies that examine the impact of external

assistance over time, despite the fact that most theorising characterises this as the initial phase of a trajectory of change involving subsequent cognitive restructuring.

The need to refocus research into scaffolding onto the role of linguistic mediation and the trajectory of change is highlighted by attempts to integrate it with Karmiloff-Smith's (1992) more general representational redescription (RR) model of the cognitive changes that occur as expertise in a given area of functioning increases (see for example Murphy and Messer, 2000). This model proposes a four-level sequence of development, in which initially context-bound procedural knowledge (implicit or I level representations) is transformed into increasingly explicit and more coordinated or general formulations (E level representations), making it available in a growing range of other contexts, first to the self (E1 and E2 levels) and then to others via encoding in language (E3 level). The appeal of this model as a framework for thinking about scaffolding is that it makes a deliberate connection between cognitive change and the process of rendering the form of actions explicit and, ultimately, subject to full linguistic mediation. In doing so, it carries the implication that scaffolding may be an important means by which representational redescription can be achieved (see Tolmie, Thomson, Foot, Whelan, Morrison and McLaren, 2005; Tomasello, 1999).

Not only does this framework move the role of linguistic mediation in scaffolding back to centre-stage, it also points at the forms that are likely to be important. At a root level, successful scaffolding should shape performance on an activity into an effective strategy that can be recreated on different occasions. In terms of representational redescription, this ought to be assisted by input that not only helps *operationalise* that strategy (i.e., helps the child enact a sequence of actions which the tutor knows to be expedient), but which, as part of this, provides linguistic markers or

tags for its key features so that these can be recaptured subsequently (cf. E1/E2 representations, which have similar properties, according to Karmiloff-Smith, 1992). For instance, in the context of scaffolding the solution of a jigsaw puzzle, the tutor might prompt the child to “*start* by looking for the *edge pieces*, and try to *fit those together*” (key features italicised). Beyond this, what also ought to be important is provision of more abstract or higher-level *explanations* of underlying principles, from which strategies might be recreated across a wider range of circumstances in more flexible fashion. For example, in the jigsaw puzzle context, the tutor might explain that “the basic idea is to collect pieces that have something in common, and work on fitting these together, building up the puzzle in sections”. Such explanations ought to directly promote E3 level representations, since they provide a verbal formulation that subsumes a range of more specific, context-dependent strategies.

There has been little detailed research on these possibilities so far. Evidence relating to a role for linguistic mediation in promoting improved performance has focused on explicit operationalisations rather than more abstract explanations, and the distinction between the two in terms of their range of applicability has rarely been clearly drawn. The research that has been conducted is generally supportive. Pine, Messer and Godfrey (1999), for example, found that children who saw demonstrations and heard explanations of a number of specific balance beam solutions (i.e., explicit operationalisations) progressed more than those who worked independently, although the latter children had caught up at a delayed post-test. This input apparently served at least to accelerate progress, then, suggesting that such operationalisations do facilitate learning. Similarly, Murphy and Messer (2000), found scaffolding that focused primarily on contingent application of object-specific strategies was more effective in promoting transfer of understanding of balance beam solutions than unresourced

group discussion or working alone. Peters, Davey, Messer and Smith (1999) found comparable effects for structured tuition focused on explicit operationalisations in the form of statements about strategies to be applied to different types of balance beam.

Evidence on the impact of more abstract explanations is limited. However, work by Tolmie, *et al.* (2005), in the context of training children's pedestrian skills, found clear evidence that such higher-level explanations were central to progress amongst 5- to 8-year olds working one-to-one with an adult. In the course of assisting children through computer simulation exercises designed to sensitise them to features critical to road-crossing decisions, adults' prompts were initially accompanied by general explanations of the significance of features to which they had drawn attention (e.g. "if he can't see what's coming, it's not safe"). Over the course of four sessions, however, children began to provide these explanations themselves, and the extent to which they did so directly predicted pre- to post-training improvements in performance, both on simulations and at the roadside. The generalised nature of the gains, and their association with explicit higher-level explanations, led Tolmie, *et al.* to conclude that the appropriation by children of adults' explanations had effected redescription of their representations of the road-crossing task to E3 level. A second study found less evidence of this effect, and signs that explicit operationalisations (i.e., scaffolding of context-specific strategies; cf. Murphy and Messer, 2000) were more predictive of progress. Yet, the children in this study had lower initial ability than those in the first. It was thus inferred that higher-level explanations might only be facilitative where children already possessed reasonably well-developed representations, at E1/E2 level, to provide a basis for more abstract redescription.

Whilst suggestive, however, the limited extent and disparate focus of past research makes it hard to draw firm conclusions about the impact of linguistic

mediation of either type. The present research was designed to address the need to track representational change in detail in relation to the provision during scaffolding of both explicit operationalisations (explicit guidance through an effective strategy for solving a specific problem) and higher-level explanations of general principles. Rather than imposing the occurrence of different forms of input within separate conditions, they were left free to vary within a semi-naturalistic setting (cf. Wood and Middleton, 1975; Tolmie, *et al.*, 2005). Children aged 6 to 8 years were asked to complete a series of Balance Scale problems plus the Tower of Hanoi task at three successive time-points, a few days apart. Approximately 30% of the sample received assistance on the Balance Scale at Time 1, from a parent who had received prior instruction on the principles involved, but no other guidance as to their input. The remaining children provided two forms of control condition, assistance on the Tower of Hanoi task (30% of the sample), and assistance on neither task (40%). This permitted not only the gains associated with scaffolding to be assessed, but also differences in the trajectory of change with repeated experience. The Balance Scale task was based on that devised by Siegler (1976), but in the present study children were allowed to manipulate weights on a series of pegs to achieve balance, rather than simply predicting outcomes. This task was preferred to the Balance Beam, because it permitted more precise specification of weight/distance relations.

Data analysis centred on the impact of parents' input on problem-to-problem change in children's attempts to achieve balance and in the explanations offered for solutions over successive time-points. Attention was directed, in particular, to how far children's performance varied depending on whether parental input provided, a) scaffolding of the weight x distance computations necessary to determine balanced configurations for specific problems (explicit operationalisations), and b) statements

of the torque rule specifying that balance depends in general on weight x distance products on either side of the fulcrum being equal (higher-level explanations).

It was anticipated that children who received assistance on the Balance Scale task would outperform (i.e., require fewer attempts to arrive at solutions), and display greater understanding of the task, than children in the control conditions, at least initially (cf. Pine, *et al.*, 1999, on the acceleration of gains). It was also thought likely that effects on understanding would be lagged, as a result of the time taken for appropriation to occur. Whilst it was anticipated that parental input would not be uniform, and would be contingent to some extent on children's actual performance (cf. Wood, 1986), more precise predictions with regard to the scale and effects of such variation were harder to make. The degree of benefit evidenced by children was expected to vary, though, as a direct function of parents' provision of explicit operationalisations and higher-level explanations. It was predicted, in particular, that gains in explicit representation, as measured by children's own explanations, would be directly related to parental provision of both types of scaffolding. However, in line with Tolmie, *et al.* (2005), it was expected that higher-level explanations would only promote gains among those who evidenced some explicit grasp of problem solutions, equivalent to E1/E2 level, at the outset. For these children alone, it was predicted that such explanations would result in E3 level representations which would be applied consistently across different problems.

Method

Design

The study employed a two-way mixed design, with a repeated-measures factor of time-point of testing (three sessions over the course of a week, at each of which children completed both Balance Scale and Tower of Hanoi tasks), and a between-

subjects factor of type of assistance provided by parents (Balance Scale only, Tower of Hanoi only, and none). The Balance Scale task required children to solve four problems at each time-point (the content of these being modified on successive occasions), by setting up and testing possible solutions for a given problem until balance was achieved. Assistance was provided only at the first time-point, with all children working alone at the second and third time-points. The sequence in which children carried out the Balance Scale and Tower of Hanoi tasks at each time-point was systematically varied to control for order effects. Data analysis focused on the impact of parental input on Balance Scale performance, in terms of 1) the number of attempts children made till success on a problem was achieved; 2) the proportion of attempts where performance was close to being accurate; and 3) the explanation they offered for successful attempts. Parental input was examined with regard to a) provision of explanations of the factors at work, especially via statements of the torque rule, and b) the nature of the assistance they provided for determining problem solutions, particularly in terms of making weight x distance computations.

Participants

Participants were 144 children from 10 primary schools within East Ayrshire, Scotland. There were 65 boys and 79 girls, aged between 6 years, 11 months and 8 years, 4 months, with a mean age of 7 years, 8 months. Of these, 42 children, 17 boys and 25 girls, were assisted on the Balance Scale task; 40 children, 20 boys and 20 girls, were assisted on the Tower of Hanoi; and 62 children, 28 boys and 34 girls, received no assistance. Children whose parents also volunteered to take part in the study were randomly assigned within school to one or other of the first two conditions; the remaining children were assigned to the no assistance condition. All

children had English as their main or only language, and participated with full written consent. The participating parents comprised 71 mothers and 11 fathers, of whom 34 mothers and 8 fathers provided assistance on the Balance Scale task.

Materials

The Balance Scale apparatus comprised a wooden base with two wooden blocks situated in the centre, and a beam held between the two blocks via a screw that provided a fulcrum. Eight circular pegs were positioned along the beam, with four situated at equally spaced intervals on either side of the fulcrum separated by a central space. A wooden rest fitted into the centre of the scale on either side of the wooden blocks, to prevent the beam moving when weights were placed on it. The weights were eight hexagonal-shaped, metal nuts with a circular hole in the middle. The beam was 45cm in length. Materials for the Tower of Hanoi consisted of a similar wooden frame for the standard three-peg/three-disk version of the task. A video camera was used to record children's performance.

Procedure

All testing took place individually in a separate room within the child's school. Parents providing assistance on the Balance Scale were shown the apparatus immediately prior to the first time-point of testing, and instructed that the goal of the task was to make the beam balance when nuts were placed on it. They were told that the researcher would put an arrangement of nuts on "her side" of the scale, and the child was then to make it balance solely by arranging nuts on "their side", but without simply reproducing the researcher's arrangement, as this would make the task too easy. The parents were then given a brief explanation of the torque rule, whereby

distance multiplied by weight had to be the same on both sides of the scale for balance to be achieved. Possible correct solutions for the first and second of the Time 1 problems were given as an examples. Parents were informed that their child would be asked to solve four problems of this kind in total, and that they could help their child in any way they considered appropriate.

Table 1 about here

The four problems used at Time 1 are shown in Table 1. When the parent understood their role, the researcher brought their child to the room (half of the children having already completed the Tower of Hanoi task independently immediately beforehand). The child was introduced to the task and what they had to do was explained to them. When the child understood, the camera was switched on and the researcher set up the arrangement of nuts for the first problem. The child proceeded by arranging nuts on their side of the scale in a configuration they thought appropriate, and then removing the rest to see if that solution worked. Parents assisted decision-making as they saw fit, but the process typically involved some degree of negotiation between child and parent, with the former making suggestions and the latter indicating potential modifications, until agreement on a solution to try out was arrived at. Each such effort was counted as a completed attempt, and if the scale did not balance the rest was inserted back into the equipment and the child tried again. Attempts continued until a correct solution was achieved. The only time the researcher intervened was to remind the child about the task rules if they made an illegal attempt (i.e., moving the nuts on the researcher's side of the scale, or reproducing the same arrangement). Immediately after the children had achieved a

correct solution for a problem, they were asked, “Can you tell me how you made it (the scale) balance”? Once they had responded, the arrangement of nuts for the next problem was set up. The researcher provided no feedback on solutions or explanations at any time.

Parents who assisted on the Tower of Hanoi task were similarly shown that apparatus prior to assisting their child, and informed of the goal of the task and the rules regarding the movement of disks. As before, when the parent was happy with their role in the task, it was introduced to their child and the goal and rules explained. In view of the number of moves involved, children completed only one trial per session, at the end of which they were asked to explain how they had completed the task. On completion of assisted tasks, the parent was thanked and shown out. If this was the child’s first task they were then introduced to the second, and completed that before returning to their class. Children who received no parental assistance also completed both tasks as part of a single session. In terms of administration, unassisted tasks were completed in identical fashion to assisted tasks.

A break of two days was given prior to the second time-point, and then again before Time 3. At Times 2 and 3, all children were taken out of class to work on the tasks alone, which were administered as before. As Table 1 shows, one new problem was introduced at Time 2 for the Balance Scale, and a further one was brought in at Time 3. As at Time 1, the children worked until they completed both tasks before returning to class.

Scoring

The videotapes of each session were transcribed to provide a written record of children's attempts, together with their explanations, and, where pertinent, parent-child dialogue. All coding was based on these transcripts.

Coding of attempts. Each attempt children made to solve a given Balance Scale problem was coded as being one of seven types, increasing in level of sophistication. These were based on the coding scheme used in Siegler's (1976) study. The seven levels are shown in Table 2. Since children made attempts at each problem until they were successful, they had to display a response at the highest level eventually. On the basis of this coding, two dependent measures were derived for performance on each individual problem across the three time-points: 1) *the number of attempts made*; and 2) *the proportion of attempts at either level 6 or 7*, in other words, the extent to which attempts indicated an appreciation of the need to manipulate both weight and distance, albeit without the child necessarily being able to determine their exact relation. Since a perfect performance would be a single attempt at level 7, fewer attempts and a higher proportion at level 6/7 were indicative of better performance.

Table 2 about here

Coding of explanations. Children's explanations after they had successfully solved each problem were also coded individually for level, according to the criteria below:

0 – no explanation was given (e.g., “don't know”)

- 1 – *weight explanations*: weight/number is important (e.g., “I’ve got as many on my side as you have”; “it was too heavy before, but now it’s the same”)
- 2 – *distance explanations*: distance/position is important (e.g., “I moved it in to the middle and it worked”; “mine are either side of the peg yours are on”)
- 3 – *weight/distance explanations*: weight/number and distance/position are both important, but the relation between the two is unclear (e.g., “if I put one there it would be too heavy, so I put it there instead and it balanced”; “when there were two and they were on top of each other it was too much, so I put them one apart”)
- 4 – *torque rule explanations*: weight/number and distance/position both matter, and the need for equivalent unit x distance values on both sides of the scale is explicit (e.g., “two times one for that peg is the same as one on peg 2 for my side”; “if you count the numbers for each peg and add it up, it’s the same on both sides”)

It should be noted that scoring was based on *reference* to the constructs defined at each level (i.e., their explicit salience), rather than their correct usage. In line with the system used for coding attempts, explanations that focused solely on weight were treated as being less advanced than those that referred to distance. Both Inhelder and Piaget (1958) and Siegler (1976) report that children characteristically perceive weight as salient to balance before they recognise the relevance of distance.

Coding of parental input. Parental interventions were coded according to a) the assistance they provided in children’s efforts to formulate attempts at problem solutions; and b) the explicit references to underlying factors they provided as part of this assistance. Interventions did not necessarily take the form of the explicit operationalisations or higher-level explanations that were the subject of theoretical

interest. These were, therefore, differentiated from other types of assistance and explanation, so that the relative impact of each on children's performance could be ascertained. Instances of parental explanations were coded at Levels 1 (weight), 2 (distance), 3 (weight/distance) or 4 (torque rule) of the system outlined above for children's explanations, with torque rule statements being defined as the higher-level explanations that were of focal interest. Elements of procedural assistance were coded as being one of four main types:

Direct control – interventions that directed the child to carry out a specific action without any explicit indication of the strategy being used (“put those two on peg 4”, “take that off and put one on peg 2”), or else involved the parent carrying out such actions themselves

Non-specific prompts – statements reminding the child of the general rules (e.g., “you can't do the same on your side as on that”) or otherwise blocking a move without specifying an alternative (“no, don't do that”), prompting an unspecified or general course of action (“make a start then”, “try taking one of them off”, “how about putting one nearer the middle”), or focused on broad comparison (“she's got three and you've got four”)

Nut/peg prompts – statements drawing attention to the peg arrangement and/or the position of nuts, but without indication of how this information might be used to solve the problem (“if we count out from the middle, this is peg 1, 2, 3, 4”, “how many nuts are on peg 2?”, “there's two on her peg 3 and how many on yours?”)

Weight x distance prompts – statements focused on nut x peg computations and comparisons involving these (“if there are four on peg 2, what does that make?”, “four times two is eight, and two times four is...?”, “so what does that come to on

each side?"); these were defined as constituting explicit operationalisations of strategies for solving a problem

For each parent, a count was made of the number of times each type of assistance and explanation was used across the attempts relating to an individual problem. Scores on these eight variables (i.e., four assistance and four explanation codes) for the Time 1 problems formed the raw data for subsequent analysis.

Reliability. The reliability of the coding systems was checked via independent inspection of eight (approximately 20%) of the Time 1 transcripts. Since parental input was scored in terms of frequency of each assistance and explanation code type, reliability was evaluated by computing correlations between judges' scores for each category across the jointly coded instances. The mean correlation for the four assistance codes was +.99, with values ranging from +.99 to +1.00; for the explanation codes it was +.96, with values between +.89 and +.99. All values were significant at $p < 0.005$. The agreement rate for children's explanations was 100% ($\kappa = 1.00$, $p < 0.001$). The coding of children's attempts was objective.

Results

Overview of analyses

Data analysis took place in four distinct stages. The first stage examined the profile of children's performance on the Balance Scale task across assistance condition (Balance Scale-assisted, Tower of Hanoi-assisted, and no assistance) and time-point. The objective here was to establish how far assistance on the Balance Scale task led to improved performance and understanding, and what the trajectory of change was relative to the two control conditions. The second and third stages focused on more in-depth analysis of the data relating to children in the Balance Scale-assisted condition. Stage two concentrated on the nature of the help provided by parents, how

far this varied across children, and whether such variation was contingent upon children's performance. Stage three focused on examination of problem-to-problem changes in children's performance and level of explanation, and the relation of these changes to specific elements of parental input at Time 1, especially explicit operationalisations and higher-level explanations. Finally, the fourth stage of analysis examined the differential effects of these key elements of parental input on the performance and explanations of children at different initial levels of task understanding. Results are presented below in this order.

Comparison across assistance condition

Figure 1 shows, for each time-point, the average number of attempts across all the Balance Scale problems made by children in the different assistance conditions. It also displays the mean level of explanation provided for solutions once these had been achieved. The error bars show the standard error for each data point. It can be seen from Figure 1a that Balance Scale-assisted children required fewer attempts to arrive at solutions at both Times 1 and 2, compared to those in the control conditions, who received no assistance on this task. At Time 3, control children had caught up to some extent, with some overlap between the three conditions now being apparent. A two-way mixed Anova (time-point x assistance condition) confirmed main effects of condition ($F(2,141)=9.91, p<0.001$) and time-point ($F(2,282)=7.02, p<0.01$), but also a significant interaction between the two ($F(4,282)=3.05, p<0.05$). Follow-up tests established that Balance Scale-assisted children made fewer attempts both overall and at Times 1 and 2 than those in the Tower of Hanoi-assisted and no assistance conditions ($p<0.05$, Bonferroni), but that the latter two conditions did not differ from each other at any time-point. The interaction was attributable to the two control

conditions exhibiting a decline in number of attempts Time 2 to Time 3 ($p < 0.05$ in both cases), whilst the performance of the Balance Scale-assisted children remained constant within the bounds of normal statistical variation. There were no differences between conditions at Time 3.

Figure 1 about here

Explanation levels had entirely the opposite pattern. All three conditions exhibited similar levels of understanding at Time 1, but the Balance Scale-assisted children then showed steady improvement across Times 2 and 3, whilst the control conditions remained more-or-less static. A two-way mixed Anova found no main effect of assistance condition, but a highly significant main effect of time ($F(2,282)=16.50, p < 0.001$) and interaction between time and condition ($F(4,282)=10.35, p < 0.001$). Follow-up tests showed significant increases Time 1 to Time 2 and Time 2 to Time 3 for the Balance Scale-assisted children ($p < 0.01$ for both), but no change for those in the no assistance condition, and change only Time 2 to Time 3 in the Tower of Hanoi-assisted condition ($p < 0.05$). Differences between conditions were not quite sufficient to achieve significance at Time 2, but at Time 3 the Balance Scale-assisted children differed from both the control conditions ($p < 0.05$). The Tower of Hanoi-assisted and unassisted children did not differ from each other in explanation level at any point.

The data establish clearly the general benefits of scaffolding for children's performance on the Balance Scale task, but also underline a degree of disjunction between the effects on ability to generate solutions to the different problems, and on explicit understanding of the factors at work. As far as the first was concerned,

parental assistance appeared to be effective in developing children's skills at Time 1, with the impact of this sustained over later time-points. Growth in explicit understanding tended to lag somewhat behind this, however, not manifesting fully until Time 3. Children in the control conditions showed slower improvement in solving the Balance Scale problems, but little apparent gain in explicit grasp. The implication is that scaffolding had benefits over simple experience in terms of accelerated task performance, but perhaps more importantly in paving the way for growth in explicit understanding.

Detailed analysis of change in the Balance Scale-assisted condition

Patterns of parental assistance. Parental input showed substantial and apparently systematic variability in provision of procedural assistance and explanations at Time 1. Only 15 parents made use of explicit operationalisations in the form of weight x distance prompts, of whom only 13 also made use of the higher-level torque rule explanations. No other parent provided explanations at this level. Of these 13 parents, four gave other less specific explanations more frequently than torque rule statements, potentially diluting their impact (although all did refer to both weight and distance as factors). These four parents, and the two who used explicit operationalisations without torque rule explanations, also made more use of the less explicit nut/peg and non-specific prompts than weight x distance prompts. These characteristics defined two categories of input style, as follows:

- 1) *Fully explicit input:* procedural assistance via a focus on weight x distance prompts (explicit operationalisations), with torque rule (i.e., higher-level) explanations predominant (n=9)

- 2) *Partially explicit input*: procedural assistance via nut/peg and non-specific prompts predominantly, with weight, distance, and weight/distance explanations most frequent (n=6)

Of the remaining 27 parents, 16 gave non-specific prompts for 30% or more of their input, and weight explanations for 10% or more, with a clear preponderance (60% or more) of all their input being of these two kinds. For the final 11 parents, input was characterised by a substantial percentage of input (20% or more) taking the form of direct control. Some, though not all of these also gave substantial numbers of weight explanations. These characteristics defined two further categories of input style:

- 3) *Minimally explicit input*: primarily non-specific procedural assistance, with weight explanations predominant (n=16)
- 4) *Implicit input*: substantial direct control, with some weight explanations (n=11)

No parent was assignable to more than one category, but in order to confirm the validity of the categorisation, the data were subjected to a discriminant function analysis. This used the four categories defined above as the target grouping variable, and frequency of the four procedural assistance and four explanation codes as raw input. The analysis identified three significant discriminant functions accounting for 100% of the variance, with the first loading on weight x distance (0.42) and nut/peg prompts (0.78), the second on torque rule explanations (-0.69), and the third on direct control (0.84) and weight explanations (-0.29). It will be noted that the first function reflects the distinction between fully or partially explicit input and minimally explicit or implicit input, the second between fully and partially explicit, and the third between minimally explicit and implicit. Of the 42 cases categorised as described above, only one was identified by the analysis as a potential misclassification (the implicit input

case with the lowest percentage of direct control, which might equally have been classed as exhibiting a minimally explicit style). Relevant means for each category of input style on the eight variables are shown in Table 3. The high standard deviations associated with many cells reflect the fact that whilst *relative* occurrence of input of different types within style categories was of the pattern specified, the exact *extent* of input varied from parent to parent. Analysis of relations between elements of parental input therefore controlled for this variation.

Table 3 about here

Despite the variation between parents in input style, there were only limited signs that they varied their approach from problem to problem, although this might be expected if the type of assistance offered were contingent upon children's performance (cf. Wood, 1986). Two-way mixed Anovas (problem x input style) on each of the parental codes found a main effect of problem and a problem x input style interaction only for weight x distance prompts ($F(3,114)=6.36, p<0.01$, and $F(9,114)=3.68, p<0.001$), and a further main effect of problem for torque rule explanations ($F(3,114)=5.36, p<0.01$). Parents who used these elements (i.e., those with fully and partially explicit input styles) provided them more often on later problems, especially problem 3 (for weight x distance prompts, mean=1.00, 1.59, 2.31, 2.24 for problems 1 to 4; for torque rule explanations, mean=0.21, 0.29, 0.55, 0.26), perhaps indicating a 'hammering home the point' strategy. Even then, they were broadly consistent in the scale of their use of weight x distance prompts across problems, with significant correlations being identified between problems 1 and 4

($r(12)=0.68$, $p<0.01$) and 2 and 4 ($r(12)=0.78$, $p<0.01$), controlling for overall level of input (one-tailed in both cases).

For torque rule explanations, consistency of deployment across problems was less, with significant correlation only between problems 2 and 3 (partial $r(12)=0.46$, $p<0.05$, one-tailed). Since such explanations were only correlated with weight x distance prompts on problem 1 (partial $r(12)=0.79$, $p<0.001$, one-tailed), the data indicate that parents who used both explicit operationalisations and higher-level explanations tended to provide the whole framework of assistance and explanation on problem 1. They then persisted primarily with the first element, only providing explanations as they felt necessary to reinforce the rationale for the weight x distance computations. Variation in input that might indicate contingency upon children's performance was thus only apparent for torque rule explanations. No effects of problem were found for any of the other elements of parental input, and use across problems was generally well-correlated.

Problem-to-problem changes in children's performance and level of explanation. Table 4 presents a detailed breakdown of each child's number of attempts and explanation level on problems 1 to 4 at Times 1 to 3. To help clarify effects of parental input, children are grouped according to which input style their parent exhibited. Means across children and problems for each time-point are shown in Table 5. The presence of systematic trends within these data was examined by means of doubly-repeated three-way mixed Anovas (problem x time-point x input style), coupled with specific correlational analyses.

Tables 4 and 5 about here

a) Attempts. As far as number of attempts was concerned, this analysis revealed a main effect of input style ($F(3,38)=4.35, p<0.05$), with follow-up tests showing that children made fewer attempts if their parent adopted a fully explicit input style than if they adopted an implicit style ($p<0.05$, Bonferroni; all other difference ns). As can be seen from Table 4, the former style dramatically constrained attempts at Time 1, where the modal performance was a single correct effort. Even at Times 2 and 3, though, this remained a frequent outcome for children in this grouping, despite the substantial increase in attempts shown by some. Children whose parents used a partially explicit style also made fewer attempts at Time 1, but this initial constraint was not as marked. Children whose parents used minimally explicit or implicit styles in contrast showed no corresponding constraint at Time 1, and this difference gave rise to an interaction between input style and time-point ($F(6,76)=2.24, p<0.05$) in addition to the main effect of input style (see Table 5).

The analysis also revealed a main effect of problem ($F(3,114)=3.43, p<0.05$), and an interaction between problem and time-point ($F(6,228)=2.53, p<0.05$). These effects were attributable to the average number of attempts tending to be higher on problem 1 (means=7.23, 4.67, 5.41, 5.51 for problems 1 to 4, averaged across time-point), and to this pattern becoming more pronounced at Time 2 (means=10.05, 4.73, 6.64, 5.10). As Table 4 makes clear, there was in fact substantial variation in this effect, with children who experienced implicit or minimally explicit assistance showing erratic variation problem-to-problem in number of attempts at Time 1 in particular. The average pattern held better at Time 2, with 17 out of these 27 children especially tending to make their peak number of attempts on problem 1 or problem 2. At Time 3, the majority of children made their largest number of attempts on either problem 1 or problem 4, the latter being somewhat more likely among those who had

originally experienced minimally explicit or implicit assistance. These children also exhibited some tendency to make their peak number of attempts at roughly the same point in the problem sequence across successive time-points.

The broad picture, then, was that parental input constrained attempts, but only if it was at least partially explicit in style. In the absence of such assistance, children often spent at least one problem of a session, frequently the first, exploring or reorienting to the task before making more targeted efforts, though gains were often not sustained in any systematic fashion through to the next session. The relation between attempts and degree of targeting was borne out by the proportion of attempts at level 6/7, since these were significantly negatively correlated with the number of attempted solutions for every problem, except the fourth at Time 1 ($r(42)$ ranged between -0.22 and -0.71, average=-0.46). The greater the focus, the fewer the attempts needed to arrive at a solution, and conversely, the less clear children were about where to focus their efforts, the more attempts they made.

b) Explanations. The pattern for change in explanation level differed in as much as systematic shifts took place solely in relation to time-point. Analysis showed a main effect of time-point ($F(2,76)=23.50$, $p<0.001$), in line with the upwards trend seen in Figure 1b, but also an interaction between time-point and parental input style ($F(6,76)=2.82$, $p<0.05$). As can be seen in Table 5, children who were assisted by fully explicit input showed a steep increase to Time 2, whereas progress was more gradual, and to a somewhat lower level, for those whose parents gave partially or minimally explicit assistance. For children whose parents relied on implicit assistance, progress was delayed till Time 3.

Inspection of the individual data in Table 4 bears out the general trends. First, in terms of consistency of explanation level across problems, virtually all children gave

at least two explanations at the same level at all three time-points, with exactly half giving three or more the same at Times 1 and 2, and nearly two-thirds (27) doing so at Time 3. Secondly, with regard to the effect of parental input, whilst the pattern was not uniform, children whose parents gave fully explicit assistance were the only ones who themselves gave torque rule explanations at Time 2. Moreover, the presence of explanations at this level at both Times 1 and 2 (as measured by the number of problems for which children gave them) was significantly correlated with the total number of torque rule explanations provided by *parents* ($r(42)=0.26$, $p<0.05$ and 0.36 , $p<0.01$ respectively) and the number of weight x distance prompts they made ($r(42)=0.37$, $p<0.01$ for both), the two defining characteristics of this style of input. Children's torque rule explanations at Time 3, in contrast, were only significantly correlated with their *own* use of these explanations at Time 1 ($r(42)=0.40$, $p<0.01$) and Time 2 ($r(42)=0.91$, $p<0.001$; all analyses one-tailed), providing clear evidence of the predicted process of appropriation.

It should also be noted that the effect of parents' provision of torque rule explanations and weight x distance prompts appeared to be cumulative and lagged, again consistent with a process of appropriation. Whilst total provision predicted total child use of torque rule explanations at Time 1, this association was absent on any individual problem. Instead, weight x distance prompts and parental torque rule explanations typically predicted child use of torque rule explanations on *subsequent* problems. Thus problem 1 usage by parents was associated with child torque rule explanations on problems 2 and 3 (for weight x distance prompts, $r(42)=0.49$ and 0.65 respectively; for parental torque rule explanations, $r(42)=0.67$ and 0.56 , $p<0.001$ in each case). A similar relation was present for weight x distance prompts on problem 2 and child torque rule explanations on problem 3 ($r(42)=0.52$, $p<0.001$). Conversely,

the only sign of parental usage being contingent on children's performance was that child torque rule explanations on problem 3 predicted weight x distance prompts and parents' torque rule explanations on problem 4 ($r(42)=0.60$, $p<0.001$ and 0.36 , $p<0.01$ respectively; all analyses one-tailed). However, the relation was *positive*, consistent with 'hammering home the point', not a response to faltering on the part of the child.

c) Relations between attempts and explanations. The difference in pattern of change for performance and explanations begs the question of what relation, if any, the two had to each other. The data in fact indicate a complex relation that shifted across problems. At Time 1, children's explanation level was inversely related to attempts and proportion at 6/7 on problem 1, i.e., the higher the explanation level, the *more* the attempts ($r(42)=0.38$, $p<0.01$), and the *less* the focus ($r(42)=-0.29$, $p<0.05$). On problem 2, the relation was in a more expected direction ($r(42)=-0.27$ and 0.30 respectively, $p<0.05$ for both), but on problems 3 and 4, there was no significant relation at all. At Time 2, the pattern was similar, explanation level being strongly related to attempts and proportion at 6/7 on problem 1 ($r(42)=-0.42$ and 0.40 , $p<0.01$), but the effect weakening to zero by problem 4. At Time 3, the impact of explicit grasp was maintained until problem 3 ($r(42)=-0.37$, $p<0.01$ and 0.34 , $p<0.05$; all analyses one-tailed), and only lost at problem 4. Since attempts generally *improved* across problems as the relation to understanding weakened, this suggests that performance typically ran in advance of explicit grasp, though the two were better coordinated by Time 3.

This pattern was different for children who received fully explicit assistance, though. At Time 2 the relation of explanation level to attempts maintained until problem 4 (as at Time 3 in the overall sample), whilst at Time 3 the relation persisted after problem 1 ($r(9)=-0.38$, ns, -0.85 , $p<0.01$, -0.74 and -0.69 , $p<0.05$ for both; all

one-tailed). The evidence is thus consistent with appropriation of torque rule explanations by these children having accelerated relations between understanding and performance, and for these children having finally generated genuine E3 level representation capable of consistently guiding decisions.

Children who did not receive fully explicit assistance also benefited from intervention relative to children in the control conditions, however. The general pattern suggests progress for them occurred primarily via increasing approximation of attempts to correct solutions (perhaps based on attention to the rate at which the scale fell on unsuccessful efforts). This appeared to be followed by consolidation of the lessons learnt from such experience prior to the next set of trials, this grasp being superseded gradually by further exploration during those trials. The implication is that attempts at level 6/7, which indexed such approximation, were central to progress. If parental input had a positive effect for these children, then, it must have been via an impact on the proportion of such attempts. The only element of parental input that had this relation was nut/peg prompts, totals of which were correlated with mean proportions of level 6/7 attempts at Times 1 and 2 among those not in the fully explicit grouping ($r(33)=.36, p<0.05$, and $.56, p<0.01$, both one-tailed). These prompts were of course present in all input styles, although only infrequently so for those who received minimally explicit or implicit assistance.

Effects of explicit explanation on higher- and lower-performing children. It had been predicted that the impact of higher-level explanation by parents would differ according to whether children's initial understanding of the task was at level I or E1/E2. To examine this, the Balance Scale-assisted children were divided into two groups, according to whether or not they made attempts scored at level 3 or below (see Table 2) during the first problem at Time 1. Since these essentially constituted

trial-and-error activity, they were unlikely to have been promulgated by parents, and would not be expected to be produced by children at level E1/E2: explicit representation should lead to more systematic behaviour, even if this is limited in terms of the principles manipulated. Of the 42 children, 20 produced attempts at level 3 or under on the first problem, and were categorised as lower-performing; whilst 22 produced attempts only at level 4 and over, and were categorised as higher-performing.

Children's classification as higher- or lower-performing is indicated by the prefix H or L in Table 4. It will be apparent from this table that while the four input styles were all found among parents of both higher-performing and lower-performing children, there was nevertheless considerable difference in their exact distribution. In particular, fully explicit assistance occurred predominantly among higher-performing children, whereas implicit assistance occurred mostly among the lower-performing. This association was significant ($\chi^2(3)=10.08$, $p<0.05$), and does not appear to be explicable in terms of input style itself creating the basis for children's categorisation, as it predicted neither the number of attempts at level 3 and under, nor at level 4 and above on problem 1 at Time 1. The implication is that whilst problem-to-problem contingency between children's performance and parental input was broadly absent, it appeared to operate at the more general level of children's initial capability on the task.

One consequence of this difference in distribution was that lower-performing children had significantly less exposure to torque rule explanations (mean=0.45 vs 2.09; $F(1,40)=4.73$, $p<0.05$), since these only occurred in input styles that were less common among their parents. Thus the evidence on the key point of interest is restricted. As far as it is available, however, it is supportive of the hypothesis that

appropriation is dependent on level of grasp. The positive correlations between parental torque rule use and child use at Times 1 and 2 were maintained at the same level when the higher-performing children alone were considered ($r(22)=0.32$ and 0.31 respectively, $p<0.1$ for both), but not among the lower-performing ($r(20)=-0.10$ at Time 1, ns; Time 2 value is not computable as torque rule explanations were not given here by these children). The same pattern obtained for weight/distance explanations, where there was no difference in exposure between the two sub-groups. For the higher-performing children, parental use of these was correlated with their own use at Time 1 ($r(22)=0.49$, $p<0.05$) and to a lesser extent at Time 2 ($r(22)=0.35$; $p<.1$). For lower-performing children, these correlations once again disappeared ($r(20)=0.16$ and -0.04 respectively, both ns).

Discussion

The data reveal a complex interactive relation between type of parental input, children's attempted solutions and their explanation level, the precise nature of this relation shifting over time, with the impact of parental input still being felt at Time 2, but dwindling at Time 3. Despite this complexity, in most respects the data were in line with the effects of linguistic mediation predicted to occur when parents provided assistance via explicit operationalisations of weight x distance computations and higher-level explanations.

To take the various points of correspondence in turn, the Balance Scale-assisted children showed an initial gain in focus in their attempted solutions, needing fewer efforts to arrive at answers than those in either control condition. In this respect, though, the controls caught up by Time 3 (cf. Pine, *et al.*, 1999). However, the unassisted children showed none of the gains the assisted made by Time 3 in terms of *explanations*, with these gains being present regardless of style of parental input,

albeit to differing extents. There was, moreover, some indication that they were still on an upward trend at this point. The implication is that, on the basis of simply exploring the task over three time-points, children could improve in terms of task performance and begin to carry over understanding from one problem to another, but only at a relatively inarticulate level, perhaps equivalent to E1 level representation (cf. Pine and Messer, 1999, 2003, on implicit understanding in the context of balance beam performance). Persistent gains in more explicit, E3 level representation over this time period were entirely dependent on parental input, and it was in this respect that scaffolding had its predominant impact, consistent with the proposed role of linguistic mediation.

Parental assistance was, as noted, variable in character (cf. Wood, 1986), with only two of the four broad styles identified making use of higher-level explanations that explicitly specified the relation between weight and distance. In both cases, provision of such explanations co-occurred uniquely with explicit operationalisations of weight x distance computations. It was these two elements together that were associated with the most pronounced gains in children's performance and more especially their explanations, consistent with the predicted effects of these types of linguistic mediation on representational level. This was not simply a function of rote memorisation of explanations and solutions, since children's use of the torque rule went through a subsequent period of coordination with their performance before its impact was fully felt. By Time 3, when this coordination – and E3 level representation – had been achieved, child torque rule use was only associated with their own prior use, indicating that gains occurred by means of the predicted process of appropriation and redescription. In other words, then, adult input *resourced* growth rather than promoting wholesale adoption of a new perspective.

Two other points should be noted here. One is that it was the combination of explicit operationalisation and higher level explanation that led to progress, not the latter on its own. This indicates that to be effective, reference to more abstract principles has to be connected to concrete instantiation, as Tolmie, *et al.* (2005) suggest. The other is that the effect of parents providing these two elements of input was not only lagged, as had been anticipated, but also cumulative rather than being dependent on contingent deployment, as Wood's (1986) account of scaffolding would predict. In particular, it was *total* usage that predicted gains, suggesting that consistent emphasis on the need for weight x distance computation and the principle underlying this was of greater consequence than strategic targeting of this input. Given that parental input in general tended to show consistency across problems rather than variation, and that even the less explicit styles of input were associated with progress, the data raise the question of whether the importance of contingency in previous accounts of scaffolding may have been overstated. Wood himself notes that it is difficult to achieve with any consistency, and the present data indicate that, at minimum, the process of learning via scaffolding is widely tolerant of its absence, at least at any fine-grained level.

The data are consistent with the anticipated effects of linguistic mediation in two further respects. The first is that as far as evidence was available, appropriation of higher-level explanations was dependent, as predicted by Tolmie, *et al.* (2005), on children displaying an initial level of performance consistent with at minimum E1/E2 level representation. As far as torque rule explanations are concerned, confidence in this effect is necessarily restricted by the uneven distribution of their occurrence across higher- and lower-performing children, which renders the comparison potentially unfair. The same effect was also observed, however, for weight/distance

explanations, which share with torque rule explanations an explicit reference to the combined importance of weight and distance, and thus a core aspect of the general principles at work. This comparison was not subject to concerns about uneven distribution. The implication is that, as suggested earlier, it is difficult for children to jump straight from implicit to E3 level without establishing interim representations.

The presence of this effect is an important one for various reasons. One is that it signals the capability of the linguistic mediation account to make detailed predictions that are meaningfully consistent with the general framework of the RR model, underscoring the potential power of this approach. Another is that this success in differentiating between processes that operate for children at different initial levels of representation indicates ways in which the linguistic mediation approach may go beyond the established contingency account of scaffolding. Wood (1986) emphasises the notion that scaffolding is only possible when the task is within the ambit of what the child is close to being able to do, rendering it essentially a unitary process. On the present data, though, scaffolding is also possible when the task is more removed from children's competence, but it needs to take a different form to be productive.

This point becomes evident when it is remembered that children who did not receive fully explicit input still managed to progress. They appear to have done so primarily via an approximation strategy that led to more targeted attempts in the area of a correct solution. Indeed, several children explicitly stated that this was what they were doing (e.g. "it was just another guess because of how slowly it was moving"; "that one there was too heavy cos it was too near the side so I moved it along one"). In this respect, these children may have been working in much the same way as those in the control conditions, but with one advantage. Once children start to adopt this strategy it opens the way for derivation of explicit weight/distance and even torque

rule explanations, since it involves deliberate manipulation of number and position. To achieve this shift, however, these factors have to be disembedded from the background of potential variables, and made salient. Few unassisted children managed to do this. For lower-performing assisted children, on the other hand, parents not only helped increase their focus on the range in which correct solutions might be found via nut/peg prompts, but perhaps also, by using these, explicitly indicated the features to which they needed to attend; in other words, these also served as a form of explicit operationalisation, which helped promote E1/E2 level representations. Thus even at this level, it was possible to detect a process of linguistic mediation, albeit a different one to that operating for higher-performing children.

The data still leave two issues unclear. The first is that parental provision of weight x distance prompts and torque rule explanations appeared to be *necessary* for accelerated growth in understanding, in as much as only those who received this input exhibited such change. It cannot be regarded as *sufficient* in itself, though, since it did not uniformly produce this outcome even among higher-performing children. The reasons for this individual variation are not evident on present data, though wider language ability may be a plausible factor. This requires further investigation.

The second is the rather intriguing self-selection of parental input styles, contingent upon children's initial level of representation, rather than more moment to moment variation in performance. The tendency for parents to use different styles is itself well established (see e.g., Rogoff, Matusov and White, 1996; Wood and Middleton, 1975), but this targeted adoption has been less commonly reported. The problem in the present case is that while this variation was well-predicted by children's performance level, the criteria used to categorise children were subtle, and not on the face of it very likely to have been detected by parents. This begs the

question of whether the determining factor might not in fact have been a more general (if reasonably accurate) *expectation* on the part of parents about how their child would perform. A precedent for this is provided by Rubie-Davies (in press), who reports that teachers with high expectations of their pupils provided them with large numbers of instructions and explanations about the concepts they were teaching, whereas teachers with low expectations made far more procedural statements and asked fewer questions.

This opens up the possibility that the differential pattern of behaviour and consequent impact of parental input for the lower- and higher-performing children is in part a function of a history of past parental support, and that this might therefore have been an additional source of influence on outcome in the present research. To clarify this, data from the present study need to be compared with one in which children at different initial levels work with the same, previously unknown adult. Initial level of understanding might also perhaps be established without risk of contamination (or reduced risk) by pre-testing on a closely-related, but different task, the balance beam (Pine, *et al.*, 1999). Research along these lines is currently in hand.

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Table 1. Configurations of nuts for Balance Scale problems at Times 1, 2 and 3.

Problem	Time 1	Time 2	Time 3
1	Two nuts on peg 1*	Two nuts on peg 1	Two nuts on peg 1
2	One nut on peg 2 One nut on peg 4	One nut on peg 1 One nut on peg 3	One nut on peg 1 One nut on peg 3
3	Four nuts on peg 2	Four nuts on peg 2	Four nuts on peg 2
4	One nut on peg 1 Two nuts on peg 3	One nut on peg 1 Two nuts on peg 3	Three nuts on peg 2 One nut on peg 4

*Peg 1 is nearest the middle of the scale, and peg 4 is at the end of the scale.

Table 2. Levels of scoring for children's attempts on the Balance Scale task.

Level	Description
1	Illegal moves I: manipulating the weights on the researcher's side
2	Illegal moves II: reproducing the researcher's arrangement of nuts
3	Different number and/or different arrangement of weights on different pegs to those on the researcher's side, but with unit x distance values being substantially inaccurate ($<.67$ or >1.5 times that of the researcher's configuration), indicating a trial-and-error attempt, and no conceptual understanding of the factors affecting balance
4	The same number and same arrangement of weights on different pegs to that of the researcher, implying that although the pattern of weights matter to the child, distance does not
5	A different number and/or different arrangement of weights on the same pegs to that of the researcher, indicating that distance matters to the child whereas the pattern of weights does not.
6	Different number and/or different arrangement of weights on different pegs to that of the researcher, with unit x distance values close to that on the researcher's side ($=>.67$ or $=<1.5$ times the researcher's arrangement), indicating an awareness that both weight and distance matter
7	Successful balance

Table 3. Mean frequency of elements of procedural assistance and levels of explanation provided by parents (total across problems), by input style category (standard deviations in parentheses).

Input style	Direct control	Non-specific prompts	Nut/peg prompts	Weight x distance prompts	Weight explns	Distance explns	Weight/distance explns	Torque rule explns
Fully explicit (n=9)	1.89 (1.62)	8.67 (5.98)	11.00 (4.12)	24.89 (21.17)	1.00 (1.12)	0.00 (0.00)	0.89 (1.54)	5.11 (3.02)
Partially explicit (n=6)	2.17 (2.32)	17.00 (9.74)	17.33 (9.31)	12.67 (10.31)	2.33 (3.44)	0.67 (1.03)	3.17 (4.87)	1.50 (1.87)
Minimally explicit (n=16)	2.12 (2.58)	12.81 (10.42)	1.06 (1.65)	0.00 (0.00)	7.37 (4.41)	0.94 (1.69)	1.37 (1.54)	0.00 (0.00)
Implicit (n=11)	15.91 (17.48)	12.45 (11.34)	0.54 (0.82)	0.00 (0.00)	4.91 (5.15)	0.64 (1.12)	0.54 (0.69)	0.00 (0.00)

Table 4. Number of attempts and explanation level for correct solution for each child in the Balance Scale-assisted condition, on Problems 1 to 4 (P1 to P4) at Times 1, 2 and 3, ordered by parental input style. Obvious peaks in number of attempts (2+ > minimum for a given time-point) are shown in bold.

Parental input style	Time 1								Time 2								Time 3							
	Attempts				Exp level				Attempts				Exp level				Attempts				Exp level			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
<i>Fully explicit</i>																								
H1	1	2	1	1	1	0	0	1	7	1	5	4	4	4	3	4	1	1	1	1	4	4	4	4
H10	1	1	1	1	0	0	0	4	2	1	7	2	2	2	3	3	1	4	1	2	3	2	3	3
H12	1	1	1	1	0	0	0	0	10	22	14	9	3	0	3	0	7	1	3	10	0	2	3	0
H14	2	1	1	1	0	4	4	0	11	4	1	5	2	0	4	4	4	1	37	6	3	3	0	0
H15	1	1	1	1	0	4	4	4	1	1	1	1	4	4	4	4	1	1	1	2	4	4	4	4
H16	1	1	1	1	0	1	0	3	1	1	3	1	4	4	4	4	1	1	1	2	4	4	4	4
H20	1	2	1	1	1	3	4	1	7	2	6	7	4	4	3	3	18	2	3	3	4	4	3	3
H21	1	2	1	2	0	0	0	0	8	4	3	1	0	3	3	1	13	9	4	3	0	1	3	3
L6	2	4	1	1	0	0	0	0	30	6	16	1	0	1	0	1	9	19	7	2	0	0	0	0
Mean	1.2	1.7	1.0	1.1	0.2	1.3	1.3	1.4	8.6	4.7	6.2	3.4	2.6	2.4	3.0	2.7	6.1	4.3	6.4	3.4	2.4	2.7	2.7	2.3
<i>Partially explicit</i>																								
H11	1	2	2	7	3	3	3	1	4	1	12	1	3	3	0	3	3	1	2	2	2	4	3	3
H18	5	2	1	1	0	0	1	0	19	1	22	4	3	0	0	1	19	5	11	12	1	0	2	3
H22	1	2	5	1	0	3	3	3	2	2	6	4	3	3	3	3	2	1	9	3	3	3	3	3
L9	3	2	1	1	1	0	4	4	19	6	2	6	3	3	3	3	1	1	7	14	4	3	3	3
L14	2	4	4	1	0	0	0	0	9	1	1	15	0	0	0	0	1	2	11	8	0	0	0	0
L20	6	3	5	2	0	1	3	0	8	5	1	2	3	1	3	0	1	4	3	11	3	3	3	0
Mean	3.0	2.5	3.0	2.2	0.7	1.2	2.3	1.3	10.2	2.7	7.3	5.3	2.5	1.7	1.5	1.7	4.5	2.3	7.2	8.3	2.2	2.2	2.3	2.0
<i>Minimally explicit</i>																								
H2	3	5	16	2	3	1	3	0	2	2	11	1	3	1	3	1	3	1	1	14	3	3	3	3
H4	2	6	2	9	1	1	0	0	3	2	4	2	3	3	3	3	2	3	5	6	3	3	3	3
H6	1	7	2	3	0	0	0	0	13	6	7	10	0	0	0	0	1	2	5	4	3	0	0	0
H7	2	9	4	4	0	2	0	3	11	6	2	2	1	3	0	0	19	5	14	8	3	0	0	0
H8	2	6	4	4	0	0	0	0	4	1	1	7	0	1	3	0	8	8	5	2	1	0	3	0
H9	2	2	3	6	1	3	3	3	6	5	8	2	3	3	3	3	3	1	1	4	4	3	3	3
H13	2	5	6	11	1	0	1	1	5	6	3	1	3	3	3	3	7	4	5	4	4	3	3	3
H17	1	1	4	7	0	3	0	3	19	14	5	2	1	3	3	2	13	3	2	7	3	3	3	2
H19	3	6	7	12	3	1	2	0	4	1	7	8	0	1	0	0	3	4	1	10	3	0	0	0
L2	4	2	5	8	0	1	0	1	7	7	5	1	3	0	3	0	40	12	8	8	1	1	3	3
L5	4	17	1	3	1	0	1	0	6	3	6	3	1	0	0	0	1	3	3	4	0	0	0	0
L7	4	18	2	3	0	0	1	0	14	3	5	19	1	3	1	1	4	19	1	7	1	0	3	1
L12	3	16	8	7	0	1	3	3	27	7	1	12	0	1	0	1	10	2	2	17	1	1	3	3
L13	36	11	17	19	3	2	3	0	5	8	6	5	3	2	1	3	5	7	1	2	3	3	3	0
L16	4	9	7	8	3	0	0	0	15	4	7	14	1	1	1	3	5	5	2	12	1	3	3	3
L18	2	7	5	5	0	0	3	3	2	4	12	10	3	0	0	0	1	4	1	5	3	3	3	3
Mean	4.7	7.9	5.8	6.9	1.0	0.9	1.2	1.1	8.9	4.9	5.6	6.2	1.6	1.6	1.5	1.2	7.8	5.2	3.6	7.1	2.3	1.6	2.2	1.7
<i>Implicit</i>																								
H3	2	1	1	4	0	0	0	0	4	4	3	6	0	0	3	0	1	16	1	2	1	0	2	0
H5	1	3	3	5	3	0	0	0	10	2	2	6	2	0	0	0	12	2	1	11	1	0	3	0
L1	13	5	2	8	4	1	0	0	5	2	11	2	0	0	3	3	9	2	14	2	3	0	3	3
L3	2	16	1	3	1	0	2	0	16	1	4	7	0	2	0	2	5	9	1	5	0	0	2	2
L4	6	10	1	5	0	3	3	3	26	8	7	4	0	3	2	0	13	2	1	4	1	3	3	3
L8	22	15	5	5	3	0	0	0	12	19	12	3	1	3	1	0	11	16	5	11	3	0	0	3
L10	36	7	8	45	3	1	0	3	6	3	5	17	3	3	2	3	5	1	7	12	1	1	3	1
L11	4	5	5	6	1	0	1	1	5	10	4	2	0	0	0	0	4	3	4	12	0	0	0	0
L15	11	7	11	5	0	1	0	1	19	4	13	6	2	0	0	0	3	2	8	3	0	2	2	2
L17	2	4	20	17	0	1	1	3	6	16	5	4	0	0	1	1	2	4	20	10	1	3	3	1
L19	36	13	3	5	0	0	0	0	29	4	15	3	0	0	2	3	18	2	3	3	1	3	3	3
Mean	12.3	7.8	5.4	9.8	1.4	0.6	0.6	1.0	12.5	6.6	7.4	5.4	0.7	1.0	1.3	1.1	7.5	5.4	5.9	6.8	1.1	1.1	2.2	1.6

Table 5. Mean number of attempts and explanation level at Times 1, 2 and 3, by parental input style (standard deviations in parentheses).

	Time 1		Time 2		Time 3		Overall	
	Attempts	Exp level	Attempts	Exp level	Attempts	Exp level	Attempts	Exp level
<i>Fully</i>	1.25 _a	1.08	5.72	2.67 _a	5.08	2.53	4.02 _a	2.09
<i>explicit</i>	(0.33)	(1.10)	(4.66)	(1.24)	(3.99)	(1.46)	(2.57)	(1.15)
<i>Partially</i>	2.67 _{ab}	1.37	6.37	1.83 _{ab}	5.58	2.17	4.87 _{ab}	1.79
<i>explicit</i>	(0.78)	(1.10)	(3.07)	(1.18)	(3.31)	(1.24)	(1.97)	(1.15)
<i>Minimally</i>	6.34 _{bc}	1.06	6.42	1.48 _{ab}	5.92	1.97	6.23 _{ab}	1.50
<i>explicit</i>	(4.14)	(0.75)	(2.86)	(1.02)	(3.79)	(1.07)	(2.09)	(0.79)
<i>Implicit</i>	8.84 _c	0.91	8.00	1.02 _b	6.41	1.50	7.75 _b	1.14
	(6.27)	(0.68)	(3.04)	(0.73)	(1.95)	(0.78)	(2.95)	(0.57)

Where values within the same column have different subscripts, they are significantly different at $p < 0.05$ (Bonferroni).

Figure 1 Performances across time-points by parental support condition

