The Effect of Explaining Another’s Actions on Children’s Implicit Theories of Balance

Karen J. Pine and David J. Messer

Psychology Department
University of Hertfordshire, England

Children and adults often hold naive intuitive theories about how the physical world around them works, and their misconceptions can be difficult to change. Self-explanations have been found to be effective in producing better understanding of science (Chi, de Leeuw, Chiu, & LaVancher, 1994), and explaining another person’s reasoning can also bring about cognitive change (Siegler, 1995). This study deals with one domain of physics—balance—and investigates the effects of 2 interventions on children who had either a procedure for balancing but could not explain it or had a naive theory. We pretested 140 children, ages 5 to 9 years, to assess their ability on a balance beam task and their knowledge about the principles of balance. These children were classified according to levels of representation derived from Karmiloff-Smith’s (1992) Representational Redescription model. In this sample, 104 children could not explain the principles of balance or possessed a naive theory that all things had to balance in the center. These children were allocated to 1 of 2 intervention conditions. Approximately half of the children watched the experimenter model the correct solution to the balance task; the rest observed the model and were also encouraged to produce verbal explanations of what they saw. At posttest, a significantly higher number of children from the latter condition had improved their understanding of balance. The positive effects of interpersonal explanation are discussed in relation to Karmiloff-Smith’s model of children’s development, and the implications for teaching are highlighted.

The domain of physics is an ideal one in which to study how cognitive change occurs. It is a domain in which both children and adults have been shown to hold mis-
conceptions about the world, and there has been growing interest in how these ideas become established and supplanted (e.g., Carey, 1986, 1987; Keil, 1990; Kuhn, 1989). Research on this topic has focused on two interrelated ideas: One is that these misconceptions involve naive theories, and another is that these misconceptions are part of the process of development from implicit to explicit representations. Before describing the type of intervention employed in this study, we explore in more detail these two forms of prior knowledge.

NAIVE THEORIES

When learning about the physical world, students often bring with them their own preconceived ideas; Kuhn (1989) described them as “intuitive scientists” (p. 674). Although the term theory is used to describe such prior knowledge, whether these students actually have theories remains an open question (see Carey, 1987). However, many students have one maxim that they apply indiscriminately to all problems of a particular class, and such indiscriminate application frequently results in some problems being answered incorrectly. On a balance beam task, for example, it has been found that there is a level of development when many children have a “center theory” of balance. The task requires children to balance a number of wooden beams upon a fulcrum. Some beams in the task are unevenly weighted (e.g., with a block at one end) and need to be placed upon the fulcrum off center to balance. Many children, particularly from about 6 to 7 years old, place these asymmetrical beams onto the fulcrum at the midpoint and, when they fall, report them to be impossible to balance. These children appear to hold the belief that all things balance in the middle, and this naive misconception is applied indiscriminately to all types of balance beam tasks (Karmiloff-Smith & Inhelder, 1974; Pine & Messer, 1999). Interestingly and significantly, before this age many children perform the task correctly without making the center error.

Evidence from studies investigating children’s understanding of motion also provides support for the view that children develop naive theories based on erroneous principles. Kaiser, McCloskey, and Proffitt (1986) found this in a study investigating children’s knowledge of curvilinear motion. Their task involved showing children a drawing of a curved, spiral-like tube and asking them to imagine that a ball was traveling inside the tube from the center outward. The children had to indicate the path they thought the ball would follow as it left the tube. Young children (preschool and kindergarten) predicted correctly that the ball would travel in a straight line. Yet only 25% of schoolchildren (M age = 7 years 11 months) made the correct prediction, and 75% predicted, incorrectly, that the ball would continue on a curved trajectory. Just like the balance task, in which younger children could balance all beams but most 6- to 7-year-olds made the center error, kindergarten children were better at the curvilinear motion task than older schoolchildren. Kai-
ser et al. concluded that younger children do better simply because they do not have any overarching theory of motion. Clearly, it is having a theory that can lead to errors.

One explanation of these phenomena simply could be that balance and motion are ideas that children find particularly difficult to grasp. However, the similarity and persistence of the children’s errors suggest that the problems may reflect some general learning principles (see Karmiloff-Smith, 1992). Also, reports of science misconceptions held by both children and adults pervade the literature. These include the common belief that heavier objects fall faster than lighter objects (Champagne & Klopfer, 1984), gravity forces falling objects to always follow a straight trajectory (Hood, 1995), static objects cannot exert forces (Clement, Brown, & Zietsman, 1989), or large objects must weigh more than small ones (Schauble, 1996). Such theories clearly afford children some basic, guiding principles for dealing with their environment and will be heuristically useful most of the time. However, because they are often inaccurate, erroneous, or incomplete, they also can hinder the child when formal learning about the topic is introduced (Driver, 1981; Driver & Erickson, 1983). Such theories may provide the basis for “the misconceptions that prove so resistant to teaching” (Carey, 1986, p. 1124).

**IMPLICIT KNOWLEDGE**

Prior to having a naive theory about a domain, learners might have a set of tacit or implicit procedures that enables them to solve a problem correctly without having any underlying verbalizable, conceptual knowledge about the domain. This implicit knowledge, which is not fully accessible to consciousness, is characterized by an inability to give a verbal account of the procedures used (Seger, 1994). diSessa (1983) described these knowledge layers as primitive in the sense that “they are not explicitly explained or justified within the system” (p. 15). This lack of explanation or justification has been observed in children attempting the water level task (Piaget & Inhelder, 1967). The task requires the child to anticipate the surface location of water in a tilted bottle. Children’s ability to solve this problem correctly has been found to precede their ability to provide any gravity-based justifications (Pascual-Leone & Morra, 1991; Thomas & Lohaus, 1993). Their early correct solutions have been attributed to a nonverbal, implicit understanding of gravity that is derived from their everyday experiences.

One important theory, which considers both implicit knowledge and naive theories, is Karmiloff-Smith’s (1992) Representational Redescription (RR) model. According to Karmiloff-Smith, knowledge begins at the implicit level, when there is procedural success but no higher order abstraction of principles (e.g., being able to balance all of the beams in the balance task but not being able to verbally explain the reason for the success). This is followed by Level E1 and the beginnings of an
abstraction process. At this level, a common feature is abstracted from the implicit procedures and represented as a rule. This gives rise to behavior that is driven by the rule, which can lead to errors as seen with the center error on the balance beam task and the inability to balance asymmetrical beams. At this level of abstraction, there is also the tendency to ignore counter evidence and attend only to confirmatory evidence, impeding efforts to bring about change. Thus, Level E1 in the RR model shares many features with the naive theories identified by other writers. One of the questions addressed by this study concerns how children with an implicit set of procedures for balancing objects, or those with a Level E1 center theory, can progress to having explicit understanding of the microdomain of balance. Karmiloff-Smith believed this is achieved by the recoding of knowledge into increasingly more conscious and accessible codes until it is available for verbalization. This is an internally driven process that, according to Karmiloff-Smith, is a pervasive feature of our self-organizing cognitive system; she stresses that theory-driven knowledge, Level E1 in her model, might be particularly resistant to contradictory information and, therefore, difficult to change. The claim is supported by findings from two studies that indicate that providing children with information about whether an attempt is successful does not assist their progress with the task (Messer, Mohamedali, & Fletcher, 1996; Messer, Norgate, Joiner, Littleton, & Light, 1996).

One strategy that might help children who have a center theory is to ask them to explain another person’s success in balancing asymmetrical beams. This strategy goes beyond the mere provision of feedback. The positive effect of producing explanations has been found in adult learners (Chi, de Leeuw, Chiu, & LaVancher, 1994), schoolchildren (Peters, Messer, Smith, & Davey, 1999), and preschool children (Siegler, 1995), leading us to suggest that it might provide powerful insights into how cognitive change occurs. Our particular focus is whether explanations can help bring about the transition from implicit, naive knowledge to explicit understanding. The evidence to date suggests that the process does not simply involve applying the appropriate linguistic labels but requires cognitive analysis and resynthesis of the representation (e.g., Alibali & Goldin-Meadow, 1993). Furthermore, self-generated explanations are more likely to produce conceptual understanding than explanations that echo what the child has heard from an adult or teacher because the latter may involve imitation rather than cognitive change.

In this study, children are asked to produce verbal explanations of the correct solution to a balance beam task, modeled by an adult (the Observe and Explain condition). It is hypothesized that children who have to generate explanations will improve more than children who simply watch the adult model in silence (the Observe Only condition). We hypothesize that making the children produce a verbal description of what they see will encourage them to be more cognitively active during the learning phase, to integrate new evidence into their existing knowledge, to start to form representations based on language, and to trigger the type of repre-
sentational change postulated by Karmiloff-Smith to yield better conceptual understanding. Children who simply observe a model, on the other hand, although they may be presented with nonverbal information that challenges their own conceptualization of the task, may have no mechanism for integrating the information into their own representational system and have no demands to formulate representations in terms of a language-based system.

The outcome measure in this study is children’s performance on the balance beam task and their ability to verbalize their understanding. Previous work suggests that some children will be successful at the task yet unable to talk about any of the principles of balance (see Karmiloff-Smith, 1992; Pine & Messer, 1998). These children are classified as having implicit knowledge about balancing. Improvement and conceptual change in these children can be assessed not simply by performance but by the improvement in the explicitness of their conceptual knowledge.

Previous work also suggests that there will be children who achieve partial success, being able to balance symmetrical but not asymmetrical beams, and unable to offer any explanation of their own behavior. Children who persistently use a center strategy on the balance beam task, without being able to verbalize their strategies, may be the least receptive to evidence that contradicts their center theory. It will, therefore, be informative to see whether producing explanations while observing the model can bring about cognitive change in these children or whether simply observing the correct way to balance asymmetrical beams is sufficient to prompt them to change their strategy and improve their conceptual understanding of the problem.

Our previous research (see Pine & Messer, 1998) has also found that some children can verbalize their center strategy and will say something like “you have to balance things in the middle.” These children are referred to as being at the Abstraction Verbal level because they have abstracted a rule for balancing and can verbalize it. Children who can verbalize their center theory, in contrast to those who cannot, are more likely to benefit from peer discussion (Pine & Messer, 1998) and have better transfer ability (Pine & Messer, 1999). This suggests that children who attempt to balance beams in their geometric center may have one of two distinct levels of representation (either able or unable to verbalize their strategy). Given the role of language in prompting cognitive change, it was hypothesized that children with a center strategy and some verbalizable knowledge would make better progress than children who were unable to discuss their own behavior. This contrasts with the view that all knowledge at the theory-bound stage is impenetrable and resistant to change, as Karmiloff-Smith’s (1992) model predicts.

Another cognitive advantage of being able to verbalize one’s own strategy is that this may produce knowledge that can be transferred to a related task. Siegler (1989) found that children’s verbal ability to describe a strategy influenced their subsequent application of it to new problems. This improvement in ability to transfer that accompanied verbalization was also suggested by our earlier work (Pine & Messer,
1999), which found that children at the Abstraction Verbal level, but not the Abstraction Nonverbal level, were able to transfer their center theory to another balance task. This hypothesis is tested in this study by asking whether the children in the Observe and Explain condition are better at transferring their knowledge to a picture-story task, also involving balance, than children in the Observe Only condition.

In summary, this study explores two factors that may influence children’s knowledge growth from implicit to explicit understanding of the microdomain of balance. It investigates the effects of having to explain the correct actions of a model on children’s understanding, compared with the effects of simply observing the model. Previous research into the effects of interpersonal explanation suggests that the Observe and Explain condition will produce better conceptual understanding than the Observe Only condition. A secondary issue concerns the children’s initial verbalizable knowledge and how this might mediate any learning gains. Our previous research has indicated that representations that can be verbalized are more receptive to change, and therefore children at the verbal level are expected to show greater improvement than children at the nonverbal level.

**METHOD**

**Design**

A pretest–treatment–posttest design were employed. The treatment phase had two conditions with a between-subjects design: the Observe Only and the Observe and Explain conditions. The dependent variables were the within-subjects pre- to posttest changes in the representational level and the choice of correct picture on the transfer (picture-story) task.

**Participants**

One hundred forty children from two Hertfordshire mixed infant–junior schools participated in the pretest. They ranged in age from 5 to 9 years. There were 61 boys with a mean age of 84.8 months and 79 girls with a mean age of 83.83 months.

**Materials**

For the pre- and posttest, nine wooden balance beams were used. Four were symmetrical beams: two without blocks, one with a block on either end, and one double beam. All of these balanced at their geometric center. Four were asymmetrical beams: one with one block at one end and three with two blocks at each end but varying in thickness and length. All of these balanced off center. One beam was invisibly weighted with no blocks but with lead concealed in one end, which balanced off center.
For the treatment phase, the experimenter modeled one symmetrical beam (without blocks), one asymmetrical beam (with two blocks at one end), and the invisibly weighted beam. A Panasonic VHS video camera was used to record all sessions.

Procedure

The children were taken individually to a quiet area of the school. They were seated at a table next to the experimenter. After introductions they were told, “Today we are going to be talking about balancing and playing some balancing games. Do you understand what ‘balancing’ means? What do we mean when we say that something balances?” This was to introduce the context of the task and ensure that children had encountered the term balance before. The experimenter then explained that they would be trying to get some wooden beams to balance on the fulcrum, which was indicated to the children. Children were told that the aim was to make each beam stay level on the fulcrum so it did not tip off to one side or the other.

Pretest. The fulcrum was placed before the child, and each child was asked, “Can you see if you can make the beams stay level on this bar here—that is, make them balance without falling off?” The child attempted the beams one at a time, and the experimenter encouraged the child to give explanations about how each beam balanced or, if it would not, the reason why. This was done by asking the child after a success, “How is that one balancing?” “What do you have to do to make it balance?” or “How did you do that?” Similarly, if a child failed to balance a beam, questions were posed such as, “Why won’t it balance?” “What did you do to try and get it to balance?” or “Do you think it can be balanced?”

Treatment phase. Having attempted each of the beams, the child was then randomly assigned to one of the two conditions. Because classification of the children was verified post hoc, resulting in some children being excluded from the data analysis, slightly uneven numbers remained across conditions. In all, 53 children experienced the Observe Only condition and 47 the Observe and Explain condition.

Observe Only. In this condition, when the pretest had been completed, the experimenter told the child, “Now I am going to balance some beams, and I would like you to watch carefully how I do it; then you can have another turn at balancing them.” The experimenter modeled for the child how to balance, respectively, the symmetrical beam, the asymmetrical beam, and the invisibly weighted beam. The child was not invited to comment.
Observe and Explain. In this condition the experimenter told the child, “Now I am going to balance some beams and I would like you to watch carefully and try to tell me how each one balances on the bar. Then you can have another turn at balancing them.” The experimenter modeled for the child how to balance one symmetrical beam, one asymmetrical beam, and the invisibly weighted beam and invited the child to comment on how this was done. During this session the children themselves did not attempt to balance the beams.

Posttest. The child was once again asked to balance each of the beams on the fulcrum, as in the pretest, and questions were asked to probe the child’s understanding and encourage explanations.

There was then a short debriefing session when the experimenter answered any questions the children had, praised them, and thanked them. Each child’s performance during the session was recorded on a data sheet by the experimenter and also videotaped. Analysis of a child’s balance beam performance at pre- and posttest enabled the classification of each child into one of the following representational levels:

- **Implicit**: The child is able to balance at least two of each type of beam (symmetrical and asymmetrical) but has no consistent strategy for balancing or for initially placing a beam onto the fulcrum. In addition, the child is unable to offer an explanation for his or her success (e.g., says “Don’t know” or “I just did it”), or explanations fail to include a mention of both the relevant variables, weight and distance.
- **Implicit Transition**: The child is able to balance no more than one of each type of beam but places all beams onto the fulcrum around their midpoint. Explanations are similar to those at the Implicit level (see previous).
- **Abstraction Nonverbal**: The child is able to balance at least two symmetrical beams but fails on all, or all but one, of the asymmetrical beams. There is clear evidence of a center strategy, with all beams being placed onto the fulcrum at their midpoint. The child may state that asymmetrical beams cannot be balanced but does not explain a center theory.
- **Abstraction Verbal**: Performance is equivalent to Abstraction Nonverbal level, but explanations include reference to the center strategy (e.g., says, “You have to put it in the middle”).
- **Explicit Transition**: The child is able to balance at least two of each type of beam and is able to explain a strategy for balancing both types (e.g., says, “You have to put this in the middle” for a symmetrical beam or “You have to put this one a bit more over to the side” for an asymmetrical beam). However, there is no explanation of the function of the two relevant variables, weight and distance.
- **Explicit E3**: The child is able to balance at least two, and usually all, of each type of beam, and explanations include reference to the compensatory function of the two variables, weight and distance (e.g., says, “This side’s got more weight on, so I make this side longer so that it has the same weight”).
This system of classification is based on levels derived from Karmiloff-Smith’s (1992) RR model with modifications based on empirical findings from our own research with over 300 children (Pine & Messer, 1998, 1999, 1999). The Implicit and Explicit E3 levels correspond to those identified by Karmiloff-Smith. Her Level E1 has been replaced by two levels: Abstraction Verbal and Abstraction Nonverbal. Additional transition levels have been identified through previous work and incorporated into the model. These levels have been the subject of validation by two independent raters with interrater reliability exceeding 90% (Pine & Messer, 1998). Longitudinal testing has confirmed the hierarchical ordering of the levels (Pine & Messer, 1999).

RESULTS

At pre- and posttest, children were classified according to one of the following representational levels: Implicit, Implicit Transition, Abstraction Nonverbal, Abstraction Verbal, Explicit Transition, or E3. This classification scheme made it possible to classify 91% of the children (127 out of the total 140). Two children did not complete the pretest and were excluded from the study, and 11 children did not fit into any of the categories mentioned and were unclassified. Thirty-six children were classified at Level E3 (i.e., having full conceptual knowledge) and only took part in the pretest and transfer task.

The Effect of the Two Conditions on Improvement

Improvement in the children was assessed via a pre- to posttest change in representational level, from a lower to a higher level within the scheme previously outlined. In the initial analysis, improvement is treated as a categorical variable, with children either improving or not improving. Alpha level for all tests was set at .05.

In the Observe Only condition, 22 children out of 44 improved (50%). In the Observe and Explain condition, 28 children out of 40 improved (70%). A chi-square analysis of these frequencies found that their distribution was significantly different to that expected by chance, $\chi^2 (1, 84) = 3.95, p \leq .05$. Significantly more children from the Observe and Explain condition improved than from the Observe Only condition.

The Effect of Pretest Representational Level on Improvement

Further analysis was carried out to see whether children’s level at pretest was associated with improvement at posttest. For relevance and brevity, we focus on children who were either at the Implicit level (i.e., were able to balance the beams but
had no verbalizable knowledge) or children who had a center theory, which could either not be explained (Abstraction Nonverbal) or could be explained by the children (Abstraction Verbal).

At the Implicit level, 55% of the children improved; at the Abstraction Nonverbal level, 37% of the children improved; and at the Abstraction Verbal level, 88% of the children improved (see Table 1). Chi-square tests of all of the frequencies in Table 1 were conducted. For the Implicit and Abstraction Nonverbal levels, observed frequencies did not differ significantly from those expected by chance, but at the Abstraction Verbal level, significantly more children improved than did not, $\chi^2(1, 25) = 12.98, p \leq .05$.

The Interaction of Condition and Pretest Level

This analysis examined whether children at different representational levels were similarly affected by the conditions (see Table 2). There were only small numbers of children at the Implicit ($n = 11$) and Implicit Transition levels ($n = 9$) at pretest, which precluded any statistical analysis of these data. A larger proportion of children ($n = 52$) began with a center theory of balance, either verbally stated (Abstraction Verbal) or not (Abstraction Nonverbal), and it is these children that the next section of the analysis considers.

The effect of the conditions on children at the Abstraction Nonverbal level. In the Observe Only condition, 2 children out of 14 improved (14%), whereas in the Observe and Explain condition, 8 out of 13 children improved (62%). The distribution of improvement as a consequence of the two conditions was significantly different from that expected by chance, $\chi^2(1, 27) = 6.45, p \leq .05$.

The effect of conditions on children at the Abstraction Verbal level. At the Abstraction Verbal level, 13 out of 14 children improved in the Observe Only

<table>
<thead>
<tr>
<th>Level</th>
<th>Improved</th>
<th>Did Not Improve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implicit</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Abstraction Nonverbal</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Abstraction Verbal</td>
<td>22</td>
<td>3</td>
</tr>
</tbody>
</table>

$^a n = 11. ^b n = 27. ^c n = 25.$
condition (93%), and 9 out of 11 improved in the Observe and Explain condition (82%). Chi-square analysis found the association between condition and improvement was not significant, $\chi^2(1, 25) = .71$, $p = .39$. As Table 2 shows, improvement at this level appears to have occurred irrespective of the condition that was experienced.

A comparison of the Abstraction Nonverbal and Verbal levels revealed a striking difference in the effect of the Observe Only condition. At the Abstraction Nonverbal level, only 2 out of the 14 children improved in this condition, whereas at the Abstraction Verbal level, 13 out of 14 improved. This proved to be highly significant, $\chi^2(1, 28) = 12.90$, $p \leq .01$. These data highlight an important distinction between the Abstraction Nonverbal and Abstraction Verbal levels, in that the former appears to be more resistant to input than the latter as well as less likely to show improvement, especially in the Observe Only condition. The greater gains for Abstraction Verbal over Abstraction Nonverbal, regardless of condition, suggest that knowledge that is verbalizable is more likely to be improved on than knowledge that is not. Thus, the requirement to provide a verbal explanation is especially important for children whose theories are not readily accessible.

The effect of the two conditions on the amount of improvement. In the next analysis, we tried to quantify how much progress the children made in terms of how many levels they advanced after experiencing one of the two conditions. A two-factor analysis of variance was conducted to test the effect of pretest level (five levels) and condition (two levels, Observe Only and Observe and Explain) on the number of levels the children advanced from pre- to posttest. It is informative here to look at the difference in pre- to posttest means produced by each condition at each

<table>
<thead>
<tr>
<th>Level</th>
<th>Improve?</th>
<th>Observe Only Condition</th>
<th>Observe and Explain Condition</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implicit</td>
<td>Yes</td>
<td>3</td>
<td>3</td>
<td>&gt;</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Implicit Transition</td>
<td>Yes</td>
<td>3</td>
<td>4</td>
<td>&gt;</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Abstraction Nonverbal</td>
<td>Yes</td>
<td>2</td>
<td>8</td>
<td>.0111</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>12</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Abstraction Verbal</td>
<td>Yes</td>
<td>13</td>
<td>9</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Explicit Transition</td>
<td>Yes</td>
<td>1</td>
<td>4</td>
<td>&gt;</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Note. $>$ represents numbers in the cells were too small to compute a statistical test.
level. In Figure 1, a comparison of the paired (shaded and unshaded) bars at each level indicates the effectiveness of the intervention.

There was found to be a main effect of pretest level, $F(4, 74) = 7.62, p = .0001$, although this is not surprising because lower levels had the scope to move up more levels than higher levels. However, there was also a main effect of condition, $F(1, 74) = 8.96, p = .003$, with the Observe and Explain condition producing significantly more change than the Observe Only condition. Thus, in addition to the earlier analysis, which found that the Observe and Explain condition produced more children who improved, this analysis showed that the amount of improvement made by each child was also greater in the Observe and Explain condition. The interaction of pretest level and condition approached but did not reach significance, $F(4, 74) = 2.22, p = .075, ns$.

The effect of the conditions on amount of improvement in children at the Implicit level. In relation to these data, it is instructive to examine the effects of condition on each of the levels. Children who were at the Implicit level at pretest improved by a mean of 1.5 levels if they experienced the Observe Only condition; 2.5 levels if they were in the Observe and Explain condition. This suggests that simply observing the model triggered redescriptions of children's implicit knowledge, and if children had to give an explanation, the redescriptions was slightly greater, although not significantly so.
The effect of the conditions on amount of improvement in children at the \textit{Implicit Transition level}. The greatest effect of condition appears to be at the Implicit Transition level in which children improved 1.6 levels ($SD = 1.94$) after the Observe Only condition but 3.5 levels ($SD = 0.57$) after the Observe and Explain condition. Therefore, the Observe and Explain condition was responsible for these children progressing by nearly 2 whole levels more than the Observe Only condition, post hoc contrasts, $F(1, 7) = 4.03, p = .04$. This suggests that before the center theory has developed, and while the process of abstraction is just beginning, children’s representations are still susceptible to input, and intervention can be very effective. Alibali and Goldin-Meadow (1993) suggested that transition phases of development indicate that the child is ripe for training, and our findings endorse that view. Our data suggest that considerable gains can be made if the child is pushed to make knowledge explicit at this stage, as in the Observe and Explain condition.

The effect of the conditions on amount of improvement in children at the \textit{Abstraction Nonverbal level}. For children who were at the Abstraction Nonverbal level at pretest, after the Observe Only condition there was a mean regression in terms of level ($M = .057, SD = 1.399$), whereas after the Observe and Explain Condition there was a mean improvement of approximately one level ($M = 1.154, SD = 1.573$). Post hoc contrast tests were highly significant, $F(1, 25) = 10.08, p = .002$; thus, the two conditions had significantly different effects on children at the Abstraction Nonverbal level. Although progress from this level was least likely, when it did occur it was a small gain and was more likely to be a consequence of the Observe and Explain condition.

The effect of the conditions on amount of improvement in children at the \textit{Abstraction Verbal level}. The effect of the conditions diminished considerably at the Abstraction Verbal level, and there was no significant difference across conditions, post hoc contrast, $F(1, 23) = .51, p = .473, ns$. Although the earlier analysis showed that children at this level were significantly more likely to improve, this analysis showed that the amount of improvement was not a function of the condition experienced.

The effect of the conditions on amount of improvement in children at the \textit{Explicit Transition level}. There was some regression observed in children at the Explicit Transition level at pretest, if they experienced the Observe Only condition, but slight improvement after the Observe and Explain condition. However, these means did not differ significantly, post hoc contrast, $F(1, 10) = 2.01, p = .16$. 

The effect of explaining another’s actions
DISCUSSION

This study set out to explore whether generating interpersonal explanations produced cognitive change in children who had implicit knowledge of balance or a naive center theory of balance. The aim was to see whether the children’s understanding would improve more as a result of observing and explaining the actions of an adult model as compared with observing in silence. It was recognized that the effects of the two conditions might differ according to the status of the children’s initial knowledge. Because access to language was thought to indicate greater likelihood of change, it was predicted that children who could verbalize their own naive theory (i.e., those at the Abstraction Verbal level) would be more likely to make progress than children who could not (i.e., those at the Implicit or Abstraction Nonverbal levels).

These experimental hypotheses were supported. Overall, the Observe and Explain condition produced significantly more children who improved than did the Observe Only condition, supporting other researchers’ findings regarding the positive effects of self-generated explanations (e.g., Chi et al., 1994), particularly interpersonal explanations (Siegler, 1995). Self-generated explanations may be effective when the learner is succeeding at the task, but in this study eliciting interpersonal explanations conferred the additional advantage of asking children to explain a solution more advanced than their own. As well as investigating the question of whether explaining another person’s actions could advance children’s understanding of the balance problem, we were also interested in the effect of this strategy on children who held a naive theory about the microdomain of balance, which research has suggested may be particularly resistant to change.

More than 50 of our participants started the study by operating with the maxim that all beams should balance at their geometric center, causing them to fail to balance the asymmetrical beams. Because naive theories in science have been found to be extremely robust and resistant to change, we asked whether the positive effects of interpersonal explanations would extend to this group. Interestingly, it was found that resistance to change was related to the children’s ability to verbalize their theory, with those who could explain their center theory at pretest improving more than those who could not. Children who were at the Abstraction Verbal level at pretest were significantly more likely to improve than those who were at the Abstraction Nonverbal level. Children who could not verbalize their center theory at pretest did significantly better if they were in the Observe and Explain condition, whereas those who could verbalize their theory generally made progress irrespective of condition.

The interaction of level and condition illustrate how, when learning gains are assessed, the child’s initial representational level may be as potent a variable as the type of intervention applied. In this study, the child’s initial level of functioning clearly mediated their ability to benefit from intervention, as did the precise form of the intervention itself.
These findings have to be integrated into what is becoming an increasingly complex picture regarding the teachability of children with naive theories about physics. Our previous research demonstrated that talking about balancing tasks with a group of peers was not enough to bring about progress in children with a naive, nonverbal theory (Pine & Messer, 1998). Similarly, this study has shown that in isolation, observing an adult modeling the correct solution is also insufficient for many children. This suggests that a combination of social (discussion–verbalization) and task (modeling–feedback) experiences may be needed to bring about cognitive change at this level. Findings from Peters et al. (1999) suggest that this is indeed the case. Children at the Abstraction Nonverbal level in their study did make progress following task-based tutorials. The “closed” nature of Abstraction Nonverbal representations means they demand maximum input to alter them. On the other hand, our data indicate that when knowledge is in the form of a naive theory that can be verbalized (Abstraction Verbal level), it is easier to change; for these children, simply observing the model was sufficient to bring about improvement.

Although it is not clear from this study exactly why a verbalizable theory is easier to change than a nonverbalizable one, Piaget (1964) drew attention to the fact that the act of verbalizing is directly associated with bringing the subconscious to consciousness (Prawat, 1989), and increasing conscious access to knowledge is equated with more explicit levels of representation in Karmiloff-Smith’s (1992) RR model. Karmiloff-Smith (1990) also suggested that verbalizations may lead to a reduction in procedural rigidity. Once the child’s ideas are conscious, they become reified as an object for cognition and can be reflected and operated on. This opens up possibilities for change because the components of ideas can then be systematically analyzed and compared with other evidence. We suggest that the positive benefits of verbalization accrue from these metacognitive functions and that children should be actively encouraged to verbalize their knowledge.

Implications can be drawn from these findings for both our understanding of conceptual change in physics and for pedagogic practice. Like adults, children clearly do hold naive ideas (some might say theories) about the physical world, and these can obstruct conceptual change. In Karmiloff-Smith’s (1992) RR model, the theory-bound level, which she calls Level E1, has been found to encompass two distinct levels of representation, one verbalizable and one nonverbalizable (Pine & Messer, 1998, 1999). These two levels of knowledge, the Abstraction Nonverbal and Verbal levels, produce identical performance but differ considerably in terms of the conscious and verbal access to the knowledge and in their receptivity to training. Thus, a further message to be drawn from this study is that performance measures only tell us half of the story about a child’s knowledge, and it is important also to take account of knowledge that the child can or cannot verbalize. Allied to Piaget’s notion of “readiness,” the Abstraction Verbal level appears to be the level at which it is relatively easy for teaching to make an impact and bring about cognitive change.
One of the educational implications of this study is that teachers need to be aware that the effectiveness of any instruction or intervention is mediated by the child’s initial knowledge state. Although other researchers have taken pains to point this out, this study highlights the importance of recognizing not only the content of the pre-existing knowledge structures but also their status in terms of explicitness. Thus, although it will be useful for teachers to recognize children’s naive theories about their physical world and understand the type of ideas that are difficult to change, children’s ability and opportunity to verbalize their knowledge also play key roles in effecting change. We are continuing to address the knowledge component in our work, which is aimed at identifying where naive theories arise in the science topics children encounter in primary school. The important instructional message from this study is that naive theories will be easier to change if children can verbalize their theories and have opportunities to explain demonstrations given by the teacher. Perhaps fewer misconceptions would persist after science lessons if the children, rather than the teachers, did most of the talking in class.

REFERENCES


