13. H. Liu, Y. He, A. E. Ribbe, C. D. Mao, *Biomacromolecules* **6**, 2943 (2005).
14. H. Liu, Y. Chen, Y. He, A. E. Ribbe, C. D. Mao, *Angew. Chem. Int. Ed. Engl.* **45**, 1942 (2006).
15. P. Yin, H. M. T. Choi, C. R. Calvert, N. A. Pierce, *Nature* **451**, 318 (2008).
16. E. Diestra, J. Fontana, P. Guichard, S. Marco, C. Risco, *J. Struct. Biol.* **165**, 157 (2009).
17. C. M. Agapakis *et al.*, *J. Biol. Eng.* **4**, paper no. 3 (2010).
18. F. J. Isaacs, D. J. Dwyer, J. J. Collins, *Nat. Biotechnol.* **24**, 545 (2006).
19. M. N. Win, C. D. Smolke, *Science* **322**, 456 (2008).

Acknowledgments: This work was supported by from the Enerbio-Tuck Foundation and the Institut Français du Pétrole Energies Nouvelles (to C.J.D.); Agence Nationale de la Recherche France, Institut National de la Santé et de la Recherche Médicale–Institut National de Recherche en Informatique et en Automatique projet d'envergure, and Axa Foundation Chair on Longevity (to A.B.L.); Natural Sciences and Engineering Research Council of Canada (to F.A.A.); and the Wyss Institute for Biologically Inspired Engineering. We thank the Harvard Medical School Electron Microscopy Center for assistance in electron microscopy, and we thank the reviewers for their insight.

Supporting Online Material
www.sciencemag.org/cgi/content/full/science.1206938/DC1
Materials and Methods
Figs. S1 to S13
References (*20*–*35*)

13 April 2011; accepted 6 June 2011
Published online 23 June 2011;
10.1126/science.1206938

Identity: Key to Children's Understanding of Belief

Josef Perner,[1,2] M. Christine Mauer,[1] Monika Hildenbrand[1]

Is knowledge structured and acquired as independent facts and concepts, as parcels of independent domains, or as domains that share conceptual abilities? For an answer, we looked at the development of two concepts, belief and identity. These concepts are not part of the same domain, but the application of both depends on the common ability to separate sense from reference. We show that both capacities become functional between the ages of 3 and 5 years, which provides empirical support for the contention that deep conceptual structures play an important role in cognitive development.

There are fundamentally different ways of how knowledge in our mind can be organized. It can be organized in independent domains, which are thought to emerge as specific adaptations designed to overcome persistent problems in the environment such as reasoning about objects, number, and other intentional agents (folk psychology) often considered to be modular. Alternatively, knowledge may be an accumulation of concepts and facts that are not grouped in domains. As a third option, knowledge may be structured in domains, which are related by shared conceptual abilities. These views influence how we think knowledge develops. Neither from a domain-neutral accumulation of individual facts and concepts nor from domain-specific modules can one expect a content-based sequence of how knowledge in different domains develops. Developmental patterns can only be explained by factors extraneous to the content of the acquired knowledge, such as learning exposure or brain maturation or architectural changes (for example, changes in memory capacity).

These positions have shaped research in children's "theory of mind"—for instance, their understanding that agents' actions are governed by mental states such as belief and desire. Research has focused on children's mastery of the false belief task, in which an agent does not witness an object's unexpected change of location and, therefore, thinks the object is still in its original location. Children are asked where the agent will go to look for the object. At 3 years, they typically incorrectly predict that the agent will go to where the object is currently located (*1*). One popular developmental view (*2*) is based on exposure history. It assumes that children understand an agent's desire before belief because desires vary with each agent, whereas beliefs tend to conform to reality for most agents. Another widespread view is that the core of a theory of mind is innately specified and matures around 18 months but depends on content extraneous factors (*3*) to completely unfold. These factors, such as memory capacity and inhibitory control (*4*), do not develop sufficiently until after age 3.

In contrast, an earlier view was that mastery of the false belief task indexes a wider metarepresentational ability (*5*–*7*). Supportive evidence came with false direction signs (*8*), which children find as difficult to understand as false beliefs (*9*–*11*). False direction signs pose the same metarepresentational challenge as false beliefs but are not mental states and hence not part of the mental domain. Problems with direction signs are shared by children with autism (*9*), who are known to have problems with false-belief tasks (*3*, *12*). A commonality between thinking about false beliefs and false signs has also been found in neuroimaging studies (*13*).

Although this evidence speaks against theory of mind being an isolated domain, one could intuitively argue that knowledge of the same domain is involved. For example, direction signs are what they are only because they are used by agents with a mind. The direction sign that wrongly shows the road to toy town off to the left only does so because it is read by its users in this way. Stronger evidence for cross-domain dependency can be obtained by showing that understanding of belief co-develops with the very generic ability of gaining information from identity statements: What could possibly be the common domain of, for example, understanding an erroneous belief and understanding that the (green) key that opens the green box and the (yellow) key that opens the yellow box are the same object? To understand the latter, it would not help to concern oneself with the potential effects of this information on other intentional agents—in contrast to a false direction sign, in which case such concerns might plausibly be helpful or even needed.

In G. Frege's analysis of identity statements (*14*, *15*), there is a deeper metarepresentational commonality between understanding what people believe and that two things are the same (identical). Both require the distinction between sense and reference as constituents of meaning. In the identity statement "the yellow key is the green key," the expressions "the yellow key" and "the green key" refer to the same external entity (a particular key). If the meaning of these expressions were understood only in terms of reference, then the identity statement would not be informative because it would reduce to "this particular key is this particular key." The statement only makes sense if one is sensitive to the fact that each constituent expression provides a different mode of presentation (sense) of that particular key to which they both refer. A helpful alternative way of dealing with this issue is the difference between "discourse referent" (Frege's sense) (*16*) and "external referent" (Frege's referent) (*17*). When speaking of "the yellow key," one creates a discourse referent—a conversational hub shared by participants for organizing information about that yellow key. A different discourse referent is created with the mention of "the green key." The identity statement "The green key is the yellow key" informs that the two discourse referents have the same external referent.

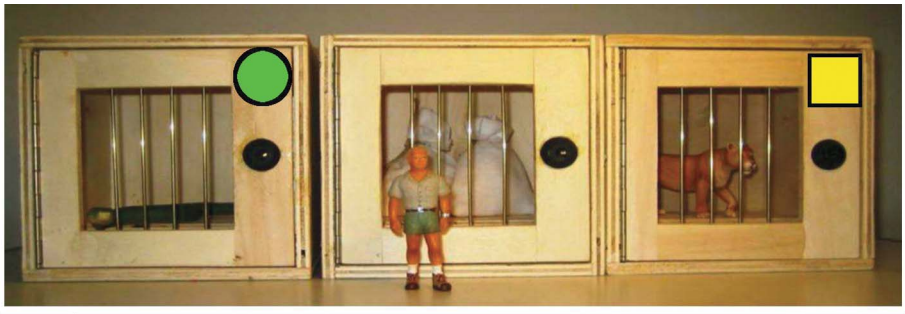
The same sensitivity to the sense-reference distinction is needed for understanding belief. For instance, children understand that when Laura wants her book, she will naturally go to the location of the book. However, when she mistakenly thinks that the book is still in the yellow box, then children have to also understand that "the location of the book" is anchored to a different external referent for Laura (the yellow box) than for themselves (the green box) and that because

[1]Department of Psychology, University of Salzburg, Salzburg A-5020, Austria. [2]Centre for Neurocognitive Research, University of Salzburg, Salzburg A-5020, Austria.

of that, she will go to the yellow rather than the green box.

In our first study, we assessed the age at which children ($n = 41$ children, 3 to 5 years old) can profit from identity information and whether this ability develops in step with their understanding of false belief. The test for understanding identity started with a familiarization with keys and locked boxes. The actual test contrasted an identity condition with a dual-function control condition in counterbalanced order and random assignment of different cover stories (*18*).

One of the stories was about helping Max the zoo keeper find the right keys for the animal cages and the food storage from a dish of unmarked keys (Fig. 1). In the identity condition, a key that opened the green snake's cage was picked from the dish. Consequently, the key was marked with a green marker on one side and put back into the dish. Then another key was selected (seemingly a new one, but it was actually the same with its yet-unmarked side up). It opened the yellow lion's cage and was, therefore, marked with a yellow sticker. As the investigator was about to put back the key, she pretended to notice something surprising, namely that the key with the yellow marker also had the green marker on its other side. She gave the key to the child to inspect and reinforced the discovery with the words: "Look: The yellow key is the same as the green key." Then, the key was put with its green side up in front of the child who was then asked (Q1) whether this (green) key opens the (yellow) lion's cage [yes], (Q2) whether it opens the food storage [no], and (3) whether it opens the (green) snake's cage [yes].



Step	Condition	
	IDENTITY	DUAL FUNCTION
1	Pick a key from bowl – try it on food box – fails – no sticker Try it on green snake's cage – fits – mark it with green sticker	
2	Return key to bowl – pick another key (is actually same but its green marker is on other side)	Flip key over – green marker not visible any more.
3	Try key on yellow lion's cage – fits – mark with yellow sticker	
4	Discover green marker on other side – hand it over to child to explore and point out the other marker and say: "Look the yellow key is also the green key."	Flip key with yellow marker over so that only green marker is visible.
5	**3 Test Questions:** Key with green side up (only green marker visible) – Does this key open ... ? • lion's cage? [yes] • food box? [no] • snake's cage? [yes]	

Fig. 1. Sequence of events in the identity and dual-function condition of study 1. (Step 1, both conditions) An unmarked key is picked from the dish and tried unsuccessfully on the food storage box. The key opens the snake's cage and is marked with a green marker. (Step 2, identity condition only) The key is returned to the dish. A seemingly new key is picked from the dish (it is the same key as before, but only the unmarked side is visible). (Dual-function condition only) The key is flipped over so that the unmarked side is visible. (Step 3, both conditions) The key is checked against the lion's cage, opens the cage, and is marked with a yellow marker. (Step 4, identity condition only) The investigator discovers the green sticker on other side and lets the child investigate the key, pointing out identity to the child. (Dual-function condition only) The key is flipped over so that the side with the green sticker is up. (Step 5, both conditions) Three questions are asked while the side of the key with the green sticker is up: "Does the key open the lion's cage?" "Does the key open the food box?" and "Does the key open the snake's cage?"

The first of these questions tested whether children had understood that the key with the green marker—being the same as the one with the yellow marker for the lion's cage—must also open the lion's cage. The second question made sure that the children realized that this key does not open just any lock, and the third tested their memory that the key with the green marker opens the cage of the (green) snake.

It is important to check whether children might have problems answering these questions not because of the identity relation involved but simply because they have difficulty understanding that a single key can open more than one cage and, in particular, that the key with the green marker can open the (yellow) lion's cage. Hence, in the dual-function control condition the investigator picked a key from the dish. It opened the snake's cage and was, therefore, marked with the green marker on one side. Then instead of being returned to the dish, the investigator tried the key also successfully on the lion's cage, and a yellow marker was put on its other side. The rest was exactly the same as in the identity condition.

Children were also given a false belief test at the end. Laura puts her book into the green box and leaves. Brother Tom enters, moves the book from the green to the yellow box, and leaves. Laura returns for her book, and children are asked to predict where Laura will look for her book (prediction question). Then, they are shown that Laura goes to the empty green box, and children are asked to explain [explanation question (*18*)]. Children who made a correct prediction (green box) and gave a sensible explanation were scored as correct.

The data show that children had a specific problem with the identity condition, which was passed by considerably fewer children than was the dual-function control (binomial test, $P < 0.001$). There was a significant improvement with age in the identity condition (Fisher's exact test, $P = 0.004$) as well as on the false belief test. The number of children passing each of these two tests closely matched, as shown in Fig. 2A. Suc-

cess in the identity condition and on the false belief test correlated substantially [Pearson's correlation coefficient (r) = 0.57] (Table 1). This relationship stayed significant even when the children's age was partialed out (r = 0.39; logistic regression, P = 0.026).

We have shown that 3-year-old children, who have little problem understanding that a key that opens the snake's cage also opens the lion's cage (dual function), have severe problems understanding the identity relation that the key that opens the snake's cage is the same as the key that opens the lion's cage. The ability to understand this identity relationship develops as children become able to understand false belief.

Study 2 was designed to test the stability of this finding by using a different technique for assessing children's understanding of identity. This made it possible to control for potentially problematic features in the key experiment in which children (and the experimenter in the child's perception) were under the mistaken impression that the yellow key is a different key from the green key. The discovery that these keys were the same led child and experimenter to revise their false belief. In the new task, no such belief revision occurred, which excluded involvement of false belief as a reason for the correlation with the belief task. Another potential problem in the first study was the need to inhibit the temptation to color match (green key for green, not for yellow cage) when children had to say that the key with its green marker visible opened the yellow cage. We could show in the dual-function control task that this inhibition was not a serious problem. Nevertheless, this time we excluded any need for inhibition.

Seventy-eight children from 3 to 6 years old were given two false belief tasks of the kind used in experiment 1, a verbal intelligence test [Kaufman Assessment Battery for Children (KABC)], and four lost-and-found stories. Two of these stories measured understanding of identity, and two were controls. Four different scenarios were used (fire station, bakery, police station, and hospital) and randomly assigned to conditions for each child.

For all lost-and-found stories (for example, firefighter), the scene consisted of a building (fire station) and an animal sitting in front of it (dog). In the identity condition, a plainclothes person described as "the firefighter" entered the scene and disappeared inside the building. Then a boy, Peter, appeared on the scene with a bag he had found. The dog told him that the bag belonged to Mr. Müller, who was inside the building, and "Mr. Müller is the firefighter" (identity statement). Peter rang the bell, the door opened, and he saw two people in plain clothes: the firefighter and another person. Children were asked "Whose bag is it?" and had to point to one of the two.

Children's ability to answer this question correctly was compared with their answers to the very same question in two control conditions. The memory control condition was exactly the same, except that the found bag was identified as belonging to the firefighter. This was to ensure that at the time of the test, children still remembered who the firefighter was.

In the attribution condition (contrast with identity condition is shown in Fig. 3), the story started with Peter finding Mr. Müller's bag. When he asked the dog whether Mr. Müller was inside the building, he was told, "Yes he is. Mr. Müller is a firefighter." When the door to the building opened, Peter saw two men, one dressed as a firefighter and another in plain clothes: "Whose bag is it?" This condition was to test that children can determine the correct external entity (one of the people in the doorway) for the discourse entity Mr. Müller when the critical information "Mr. Müller is a firefighter" provides attributive information, which can be used to identify directly the person by his (visible) attributes of being a firefighter, in contrast to the identity condition, in which the critical information expresses identity between one discourse person (Mr. Müller) and another (the firefighter): "Mr. Müller is the firefighter."

The results show good (above 88% correct) performance in the memory as well as the attribution control condition. In fact, 86% gave correct answers in both conditions as opposed to only 50% in the two identity conditions. This difference was considerably larger for the younger than for the older children (Fig. 2B). The difference between passing control and identity conditions diminished significantly with age [linear-by-linear $\chi^2(1) = 6.51$, $P = 0.011$]. Children's ability to make correct predictions in both false belief tasks was somewhat lower (37%) but not significantly so (McNemar's test, P = 0.077).

Using the most sensitive measure for individual differences, we correlated children's number of correct answers on the identity questions (0, 1, 2) with their number of correct predictions

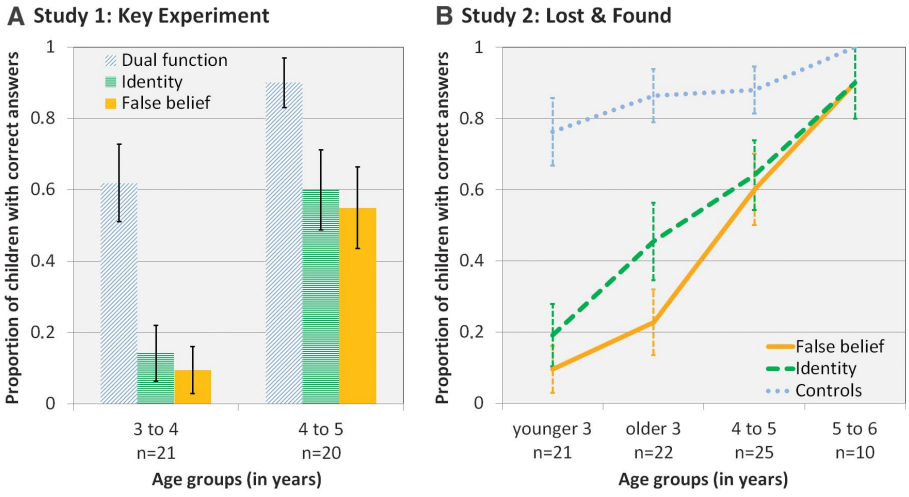


Fig. 2. Mean proportion of children passing each test. Error bars indicate the SE in each age group. (**A**) Children passed the identity test and the dual-function test, respectively, if they answered all three test questions: whether the key (with the green marker visible) opens the (i) lion cage, (ii) food box, and (iii) snake cage. Children passed the false belief test if they made a correct prediction and provided a sensible explanation of why Laura went to the empty box in search of her book. (**B**) Children passed the control tasks if they gave correct answers to "Who does the bag belong to?" in the memory and the attribution control condition. Children passed the identity test if they gave correct answers to this question in both identity conditions. They passed the false belief test if they made correct predictions in both tasks.

Table 1. Raw and partial correlations. $[.nn]_{variable}$, partial correlation after the variable has been accounted for. vIQ, verbal intelligence as assessed by the vocabulary subtest of the KABC. Dashes indicate not applicable.

	Study 1 (n = 41 children)†		Study 2 (n = 78 children)‡	
	Identity	False belief	Identity	False belief
Age	0.51**	0.59**	0.45***	0.57***
KABC	—	—	0.52***	0.69***
Identity	—	0.57**	—	0.68***
False belief	$[0.39]^*_{age}$	—	$[0.50]^{***}_{age\ +\ vIQ}$	—

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). ***Correlation is significant at the 0.001 level (2-tailed). †Levels of significance were determined by means of logistic regression. ‡Levels of significance were determined by means of t test.

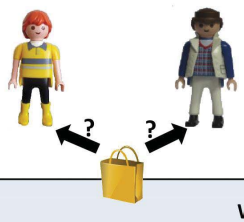
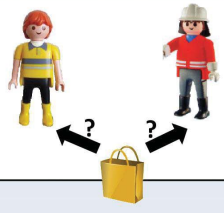
Step	Condition	
	IDENTITY	ATTRIBUTION
1	A fire station and a dog standing next to it are shown and introduced to the child.	
2	 A man in plain clothes appears and is introduced as "the firefighter." He goes inside the fire station.	
3	A boy enters the scene with a bag he has found on the way. The dog tells the boy that the bag belongs to Mr. Müller. The boy asks the dog where Mr. Müller is and the dog answers: "He is in the fire station," and adds:	
4	**"Mr. Müller is the firefighter."**	**"Mr. Müller is a firefighter."**
5	The boy rings the door bell of the fire station. The door opens, showing two men inside.	
6		
Test Question	**Whose bag is it?**	

Fig. 3. Sequence of events in the identity and attribution condition of Study 2. (Step 1, both conditions) The basic scene is introduced. (Step 2, identity condition only) A person appears, is identified as "the firefighter," and disappears inside the fire station. (Step 3, both conditions) A bag is found whose owner is given as "Mr. Müller." (Step 4, identity condition) Identity information is given that Mr. Müller is identical with the person introduced earlier as "the firefighter." (Attribution condition) Attributive information is given that Mr. Müller is a firefighter. (Step 5, both conditions) Two potential candidates for Mr. Müller are displayed. (Step 6, identity condition) The choice is between two plainclothes men, one of which is the familiar person earlier identified as "the firefighter" (Mr. Müller). (Attribution condition) The choice is between two unknown men, one of which is recognizably dressed as a firefighter (Mr. Müller). (Test question, both conditions) The child has to indicate who the bag belongs to, that is, Mr. Müller the firefighter. The additional memory control condition follows the identity condition, except for deviations in steps 3 and 4. (Step 3) The owner of the bag is given as the already known "firefighter." (Step 4) No information is given or needed. [In the original German phrasing of the question, we used "Herr Müller ist Feuerwehrmann" (approximately,"Mr. Müller is firefighter"), which brings out more clearly that an attribution is made and not an identity stated.]

and correct explanations on the two false belief tasks (range from 0 to 4). The results (Table 1, right) show in addition to study 1 that the partial correlation between false belief and identity understanding remains highly significant even after taking age and verbal intelligence (KABC) into account. This shows that the developmental relationship between understanding identity and false belief cannot be reduced to general facility with language. It is more specific.

This conclusion only holds for children's ability to predict actions and explain them as assessed by the traditional false belief test. Clements and Perner (*19*–*21*) have shown that at 3 years, the location where children predict that someone will reappear in search of an object dissociates from the location, where they expect the person to reappear (measured by their eye gaze). Such expectation may occur very early in life (*22*, *23*), whereas correct prediction can only be demonstrated well after the age of 3 years (*24*). It remains an open question whether infants' early expectations are based on the same as or a different kind of understanding [for example, behavior rules (*25*, *26*) or procedural knowledge (*27*)] than the later developing ability to predict and explain behavior.

The present data support the view that children's reasoned predictions about a person's behavior based on a mistaken belief do not develop within an isolated domain of understanding mental states but develop in unison with other domains that share needed conceptual abilities. Understanding belief relates specifically to understanding identity statements. This relationship cannot be reduced to the known relationship with general linguistic competence (*28*) or inhibitory abilities (*29*). Our contention is that the common developmental factor is a conceptual sensitivity to the sense-reference distinction.

References and Notes

1. H. Wimmer, J. Perner, *Cognition* **13**, 103 (1983).
2. H. M. Wellman, *The Child's Theory of Mind* (MIT Press, Cambridge, MA, 1990).
3. A. M. Leslie, L. Thaiss, *Cognition* **43**, 225 (1992).
4. S. M. Carlson, L. J. Moses, *Child Dev.* **72**, 1032 (2001).
5. J. H. Flavell, in *Developing Theories of Mind*, J. W. Astington, P. L. Harris, D. R. Olson, Eds. (Cambridge Univ. Press, Cambridge, 1988), pp. 244–267.
6. L. Forguson, A. Gopnik, in *Developing Theories of Mind*, J. W. Astington, P. L. Harris, D. R. Olson, Eds. (Cambridge Univ. Press, Cambridge, 1988), pp. 226–243.
7. J. Perner, in *Developing Theories of Mind*, J. W. Astington, P. L. Harris, D. R. Olson, Eds. (Cambridge Univ. Press, New York, 1988), pp. 141–172.
8. J. Perner, S. Leekam, *Q. J. Exp. Psychol.* **61**, 76 (2008).
9. D. M. Bowler, J. Briskman, N. Gurvidi, M. Fornells-Ambrojo, *J. Cogn. Dev.* **6**, 259 (2005).
10. S. Leekam, J. Perner, L. Healey, C. Sewell, *Br. J. Dev. Psychol.* **26**, 485 (2008).
11. M. A. Sabbagh, L. J. Moses, S. Shiverick, *Child Dev.* **77**, 1034 (2006).
12. S. R. Leekam, J. Perner, *Cognition* **40**, 203 (1991).
13. M. Aichhorn *et al.*, *J. Cogn. Neurosci.* **21**, 1179 (2009).
14. G. Frege, in *Philosophical Writings of Gottlob Frege*, P. Geach, M. Block, Eds. (Basil Blackwell, Oxford, UK, 1960), pp. 56–78.
15. R. May, in *Semantic Interfaces: Reference, Anaphora and Aspect*, C. Cecchetto, G. Chierchia, M. T. Guasti, Eds. (CSLI Publications, Stanford, 2001), pp. 1–62.
16. L. Karttunen, in *Syntax and Semantics, vol. 7, Notes from the Linguistic Underground*, J. McCawley, Ed. (New York, Academic Press, 1976), pp. 363–385.
17. H. Kamp, in *Propositional Aattitudes: The Role of Content in Logic, Language and Mind*, C. A. Anderson, Ed. (Center for study of language and information, Lecture Notes Series, Stanford, CA, 1990), pp. 27–90.
18. Materials and methods are available as supporting material on *Science* Online.
19. W. A. Clements, J. Perner, *Cogn. Dev.* **9**, 377 (1994).
20. T. Ruffman, W. Garnham, A. Import, D. Connolly, *J. Exp. Child Psychol.* **80**, 201 (2001).
21. J. Low, *Child Dev.* **81**, 597 (2010).
22. K. H. Onishi, R. Baillargeon, *Science* **308**, 255 (2005).
23. V. Southgate, A. Senju, G. Csibra, *Psychol. Sci.* **18**, 587 (2007).
24. H. M. Wellman, D. Cross, J. Watson, *Child Dev.* **72**, 655 (2001).
25. D. J. Povinelli, J. Vonk, *Mind Lang.* **19**, 1 (2004).
26. J. Perner, in *Cognition and Neuropsychology: International Perspectives on Psychological Science*, vol. 1, P. A. Frensch, R. Schwarzer, Eds. (Psychology Press, London, 2010), pp. 241–261.
27. R. Baillargeon, R. M. Scott, Z. He, *Trends Cogn. Sci.* **14**, 110 (2010).
28. K. Milligan, J. W. Astington, L. A. Dack, *Child Dev.* **78**, 622 (2007).
29. S. M. Carlson, L. J. Moses, C. Breton, *Infant Child Dev.* **11**, 73 (2002).

Acknowledgements: Study 1 was part of the diploma thesis of C.M., and study 2 was that of M.H., who were financially supported as research assistants by the Austrian Science Fund (project I93-G15 "Metacognition of Perspective Differences," European Science Foundation–European Collaborative Research–Consciousness in a Natural and Cultural Context). The basic idea for the study was conceived in conversations with N. Goodman and B. Rendl.

Supporting Online Material

www.sciencemag.org/cgi/content/full/333/6041/474/DC1
Materials and Methods
References (*30*–*32*)

3 December 2010; accepted 15 June 2011
10.1126/science.1201216

Identity: Key to Children's Understanding of Belief
Josef Perner *et al.*
Science **333**, 474 (2011);
DOI: 10.1126/science.1201216

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published weekly, except the last week in December, by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005.