

Divisions of the Physical World: Concepts of Objects and Substances

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Our concepts of the physical world distinguish objects, such as chairs, from substances, such as quantities of wood, that constitute them. A particular chair might consist of a single chunk of wood, yet we think about the chair and the wood in different ways. For example, part of the wood is still wood, but part of the chair is not a chair. In this article we examine the basis of the object/substance distinction. We draw together for the first time relevant experiments widely dispersed in the cognitive literature, and view these findings in the light of theories in linguistics and metaphysics. We outline a framework for the difference between objects and substances, based on earlier ideas about form and matter, describing the psychological evidence surrounding it. The framework suggests that concepts of objects include a relation of unity and organization governing their parts, whereas concepts of substances do not. We propose, as a novel twist on this framework, that unity and organization for objects is a function of causal forces that shape the objects. In agreement with this idea, results on the identification of an item as an object depend on clues about the presence of the shaping relation, clues provided by solidity, repetition of shape, and other factors. We also look at results from human infants about the source of the object/substance distinction and conclude that the data support an early origin for both object and substance knowledge.

Keywords: object concepts, substance concepts, mass nouns, count nouns

We think of some entities as physical objects that maintain their identity over time. We can ask, for example, whether a particular chair or cat is the same one we saw on an earlier occasion. We treat the entity in this way as having a causal history that persists even through changes in its material composition. However, we also can think of entities as defined by their physical composition, the material stuff that makes them up. A chair is composed of wood, plastic, or metal, and a cat is composed of tissue. This material maintains its independence from the object it constitutes. For example, the tissue that constitutes a cat gradually sloughs off while other tissue replaces it. However, this conceptual double vision poses a number of puzzles about the relation between an object and its substance. How do we conceive of the difference between objects and substances? What binds them together?

Although empirical results exist concerning this object–substance dichotomy, the findings are widely scattered in cognitive and developmental psychology. The main empirical issues center around the cues people use to distinguish objects and substances, people’s willingness to generalize the name (or the properties) of an entity to other objects or substances, their understanding of part–whole relations for these two types of entities, and the special difficulties that infants seem to experience when dealing with

substances versus objects. We know of no previous research synthesis that relates these findings. The task of this article is to provide a framework for this research that is informed by theory in neighboring disciplines.¹

We start by examine the idea that people conceive of the physical world as quantities of substance (e.g., water, iron), with some of these quantities mapping onto a separate domain of objects. This dual object/substance analysis is related to the difference between form and matter in ancient philosophy (Aristotle, 1994), but the distinction recurs in work in contemporary metaphysics (e.g., Fine, 1999; Johnston, 2006; Koslicki, 2008; Sattig, 2010), linguistics (e.g., Link, 1983), and psychology (e.g., Keil, 1979; Prasada, 1999). This framework, though, raises issues about how people think of the difference between an object and its substance and of the relation that holds between them. We developed as a working hypothesis the notion that people believe objects are shaped from their matter by a variety of physical forces, and we tried to show that this shaping hypothesis accounts for the psychological evidence on object/substance differences.

We then apply our framework to issues in developmental psychology: The way infants deal with liquids (e.g., water) and aggregates (e.g., sand). Infants follow solid objects and can anticipate the number of objects (up to three), even after the objects are hidden from their view. However, they lose track of the number of nonsolid things (e.g., piles of sand) that undergo the same treatment (Huntley-Fenner, Carey, & Solimando, 2002; Rosenberg & Carey, 2009). Why the difference? Although substances may pose special problems (Shutts,

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¹ Of course, objects are also an important topic in perceptual psychology. But because many earlier reviews (e.g., Feldman, 2003; Peterson, 2005; Pylyshyn, 2001; Spelke, 1990) have covered perceptual objects, we limit our discussion to concepts of objects and substances as they occur in language and thought. We also limit our review to physical objects, leaving aside events and abstract objects, among other entities.

Condry, Santos, & Spelke, 2009), a number of recent experiments show that infants are able to anticipate the distinctive behavior of nonsolid substances (e.g., Hespos, Ferry, & Rips, 2009). Our framework suggests that the infants' problems may lie in mapping between the object domain and the substance domain rather than in their lack of knowledge about substances.

In describing these issues, we use the terms *substance*, *matter*, and *material* as synonyms, and we oppose all three to *object*. The nature of this opposition is at the heart of our discussion.²

Concepts of Objects and Substances

We think of everyday objects as existing over time and as composed of material substance during that time. Animals and plants occupy a spatial and temporal path from their birth to their death, and during that interval, they are composed of tissue that supports their existence. Artifacts, such as toasters and teapots, similarly exist within a spatial and temporal span from their manufacture to their destruction, made up of materials, such as metal, wood, or plastic. But this commonsense way of thinking about things allows for some independence between the object and its matter. Animals and plants can survive despite having their initial stock of tissue replaced by new tissue, and many artifacts can survive an exchange of material.

In thinking about the independence of object and substance, we begin with traditional ways of drawing the distinction in metaphysics and linguistics, but we attempt to separate the parts of this tradition that accord with experimental findings from those that do not. We concur with traditional theories that objects and substances differ in that objects, but not substances, come along with a structure or relation that unifies their parts. However, we propose a new way of specifying this relation that helps explain the cues people use in identifying objects and that avoids some of the deficiencies of earlier views.

The Independence of Objects and Substances

We can picture the relationship between an object and its material as in the timeline of Figure 1. Suppose an object o exists between times t_{i-1} and t_{i+2} . We denote o at t_i as o_i , and similarly for other time points. The solid arrows in the figure connect the same object o across the points in its lifetime. Suppose, too, that at t_i , material m constitutes this object. The superimposed region in the figure represents this constitution relation. The exact nature of this relation is a matter of debate, which we consider later, but for now, we can rely on intuitive examples, such as the connection between a cat and its tissue or a cup and its porcelain. We refer to m as it exists at t_i as m_i . The dashed arrows connect this same material at different times. The figure also shows that this material—for example, a particular quantity of matter—existed before the object does and continues to exist after. So the history of the object and its material differ: Their paths converge and then diverge from left to right; during the time the object exists (from t_{i-1} to t_{i+2}), the object's material can change. The material that composes the object at one time can differ in part or whole from the material that composes it at another.

Conceptual issues about object/substance independence.

This independence of an object and its matter, however, raises some questions about our concepts of individuals. First, if an object's matter can be replaced with different matter, what holds the object together while it exists? If the replacement of matter is possible, what accounts

for our conviction that an object with material m at one time is the same as the object with new material m' later? Second, we seem to impose different restrictions on objects than on matter. For example, we do not think of the combination of Mount Rushmore and Mitt Romney as composing a single object. Some type of relation—perhaps a spatial one—has to unite the parts of a genuine object, even if we confine ourselves to the object's existence at a single point in time. But substance does not have the same restriction because we have little difficulty conceiving of scattered portions of a substance, such as water, as composing a single quantity of the substance. At t_o or t_n in Figure 1, material m may be little more than a cloud of substance, thinly spread over space. We can therefore ask whether there are *any* conceptual restrictions on substances and, if there are, how they differ from those on objects. Third, at the point at which an object is made up of a particular quantity of matter, what is the relation between the object and the matter? The matter may have existed long before the object and may exist long after the object, as in Figure 1. This difference in their histories suggests that the object is not identical to its matter. But if the object and its matter are different, then at the time at which the matter composes the object (t_i in Figure 1), we seem to have two different things (e.g., a cat and its tissue) occupying the same place at the same time.

What allows us to conceive of an object as persisting despite the possible change in its substance? In the example of Figure 1, how is it that we think of object o lasting from time t_{i-1} to t_{i+2} even though its matter varies during that period?³ We also can ask about sameness of substances over time (as Cartwright, 1965, 1970, argued). We can ask whether the material now is the same material we encountered earlier (e.g., whether the wine on the floor is the same wine that was in the glass a few minutes ago). A particular quantity of material, such as m in Figure 1, maintains its identity, despite being embodied in a particular object at one moment but not at another.⁴ What notion of substances allows us to make such assessments?

² *Substance* has a specialized Aristotelian sense in which it means a metaphysically basic being (Aristotle, 1994; Robb, 2009). But this is not the meaning we give to *substance* here. Likewise, chemists reserve *substance* to denote a molecularly uniform entity, such as H₂O, and use (*composite*) *material* for everyday stuff, such as juice; but we use *substance* and *material* interchangeably, in what we take to be their ordinary meanings. We use *entity* or *item* as a superordinate to both *object* and *substance* to have a neutral way to refer to both of them.

³ One possible answer, consistent with some recent theories in metaphysics, is that we cannot. Perhaps objects last only instantaneously so that an object at one time is never numerically equal to an object at another. All that really exist, according to such theories, are object stages, such as o_i in Figure 1, but not persisting objects, such as o . For stage theories, along these lines, see Hawley (2001) and Sider (2001). However, we will not pursue such theories here because our purpose is to explore everyday concepts of objects and substances.

⁴ One complication to the picture in Figure 1 comes from the fact that substances can change when they are brought together in an object (S. Prasada, personal communication, August 9, 2013). For example, materials such as water and other nutrients that existed in a free state at one point might combine with other substances to create tissue when they become part of an organism. If these reactions create changes to the water itself, we may be uncertain whether we have the same quantity of water now that existed earlier. However, the idea we are sketching is not committed to the notion that quantities of substance never go out of existence. Although some objects may be constituted by a quantity of substance whose existence is coextensive with that of the object, this does not call into question the possibility that other objects can survive changes in substance.

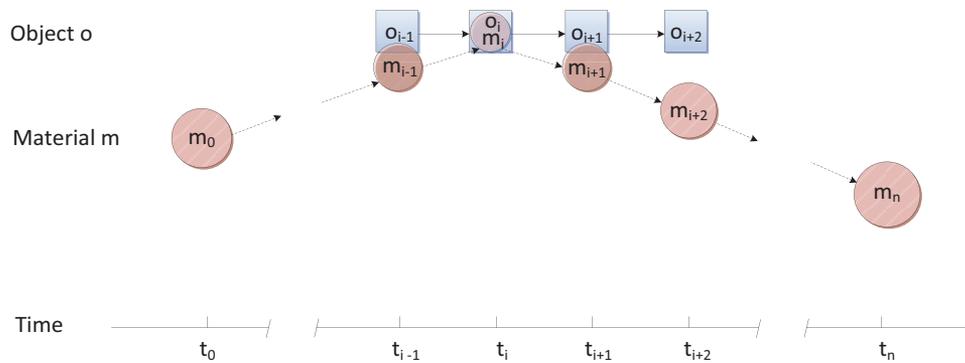


Figure 1. Hypothetical pathways for an object (o) and a quantity of material (m) over time. At time t_i the object and the material coincide (o consists entirely of m at that time). At other time points, o and m only partially overlap or are disjoint. The solid arrows trace the spatial-temporal path of the o , whereas the dashed arrows trace the path of m . See the online article for the color version of this figure.

Empirical evidence on object/structure independence. Four- and five-year-olds understand that an object's identity depends on its history rather than on its superficial appearance. They know, for example, that the history of a character (e.g., the experiences of a particular Winnie-the-Pooh doll) can give it access to knowledge about events that it does not necessarily share with even a qualitatively identical character (a second Pooh doll) (Gutheil, Gelman, Klein, Michos, & Kelaita, 2008). Children of the same age believe that objects possessing a pedigree (e.g., the U.S. President's flag pin) are more worthy of being in a museum than qualitatively identical objects with no pedigree (Frazier & Gelman, 2009). In a similar way, 6-year-olds assign higher value to pedigreed objects (a spoon said to have belonged to Queen Elizabeth) than to qualitatively identical copies. However, the same children do not favor an object with no pedigree (a spoon said to be made of silver) over a copy (Hood & Bloom, 2008). Adults, of course, also believe pedigreed objects to be more valuable than objects with no pedigree (Frazier, Gelman, Wilson, & Hood, 2009), and they do so more for works of art than for other artifacts (Newman & Bloom, 2012).

Although we know of no experimental evidence on this point, people also seem to believe that substances have histories that can confer value on them. For \$149.99, Sears will sell you "Home Plate Shaped Cufflinks made of Tiger Stadium Seat Wood," where "every pair of cufflinks includes a Certificate of Authenticity with photographic provenance of the seat wood. A set of tamper proof serial numbered hologram's accompanying each pair" (Sears, 2013). Likewise, eBay offers for \$2,800 an "authentic official Vatican real first class relic of the Noah's Ark. . . . The relic is part of the Ark, the vessel in the Genesis flood narrative (Genesis, chap. 6–9) by which the Patriarch Noah saves himself, his family, and a remnant of all the world's animals. . . . eBay policy prohibits the sale of human remains and requires a disclosure of what the relics are: these relics are a piece of wood, which are allowed by eBay policy" (eBay, 2013).

The evidence from Frazier and Gelman (2009); Gutheil et al. (2008), and Hood and Bloom (2008) shows that young children believe historical connections support the identity of objects. The same may be true of substances. But do children also

believe that an object's identity is independent of its substance? In Hood and Bloom's (2008) experiment, the children may well have supposed that matter is maintained over the course of the object's history. For example, the matter of Queen Elizabeth's spoon now may be about the same as it was when it belonged to the queen. Do people believe that an object can survive replacement of its matter? Rips, Blok, and Newman (2006) described to adult participants a hypothetical machine that was capable of copying an object's particles, transmitting the copies to a new location, and then reassembling them with the same structure. The objects' old particles were said to have been destroyed in the process; so the substance in the copy differed completely from that in the original. In one condition, for example, the original object was a lion named Fred, and participants decided whether the copy was still Fred. When all the particles in the reassembled creature were copies of Fred's particles, participants judged the creature as still Fred on over 90% of trials. ("Still Fred" decisions decreased to less than 50% when some of the particles were based on a different source—a different lion or a tiger.) Rips et al. (2006) argued that what matters for identity is the causal link between the object's stages, provided in this example by the copying process. Similar results occur for other natural kinds and artifacts in these hypothetical settings (Blok, Newman, & Rips, 2005; Liittschwager, 1995; Rhemtulla & Hall, 2009), suggesting generality over the type of object. For example, participants judge that a person can survive the total destruction of his or her body if the person's memories persist in a robot body or in a second human body (Blok et al., 2005; Nichols & Bruno, 2010). In general, then, people believe that some objects can continue to exist, despite total replacement of their original substance.

Evidence for the independence of object and matter also comes from experiments that pit sameness of substance against temporal continuity: Imagine that a ship belonging to the Greek hero Theseus was gradually remodeled by replacing each of its original planks with new ones. However, a dealer in antiquities collected the old planks as they were removed from the ship and later put them together according to the ship's original pattern. The puzzle is whether Theseus's ship is then the one with old planks (which had the same material as the original), the one with new planks (which had spatial and temporal continuity

with the original), or neither.⁵ If Theseus's ship is the one with new planks, then the identity of the ship survives a complete change in its matter (Hobbes, 1655/1839–1845). Recent experimental variations on the Ship-of-Theseus problem have substituted simpler objects for ships and have varied whether the objects are described as natural kinds or artifacts (Hall, 1998; Noles & Bloom, 2006). The results show that when the original object is a member of a natural category (e.g., a starfish-like creature), both 7-year-old children and adults believe that the successor is the object with new parts; but when the object is an artifact (a star-shaped paperweight), they believe the successor is the object with old parts. Complete detachment and reassembly may be fatal to natural kinds but not to artifacts. This evidence again confirms that, at least in the case of some natural objects, people believe survival is possible despite complete replacement of matter.

These studies suggest a role for causal forces as part of the answer to our earlier question: What holds an object together over change in its substance? The key idea is that the later stages of an object must be causal outgrowths of earlier stages (Armstrong, 1980; Nozick, 1981; Shoemaker, 1979). However, the causal chain connecting the stages must be strong enough to support identity. Earlier stages of a cat are connected in the right causal way to stages in its later life through biological processes, but the cessation of these processes at the cat's death means that nothing after this time is identical to the cat. People's descriptive knowledge of the relevant causal forces may sometimes be thin (Lawson, 2006; Rozenblit & Keil, 2002), but they may nevertheless believe in the existence of these forces. (See Rips et al., 2006, for a psychological theory of identity judgments along these lines and for a review of other factors, such as spatiotemporal continuity and category membership, that inform judgments of object identity.)

Causal forces may be responsible too for the identity of substance quantities over time. This is the idea that Hirsch (1982) advocated in explaining the identity of matter (though Hirsch adopted a different theory for objects):

[T]he only way to characterize our general procedure for judging identity of matter is to say that we reidentify matter in such a way as to arrive at the most coherent and theoretically satisfying account of what we observe. In this way we arrive at various principles which, both at the commonsense level and at the scientific levels, specify how bits of matter of various sorts may be presumed to behave under different observable circumstances. (p. 120)

But if people use causal theories to identify both objects and substances, then to account for divergences between them, as that depicted in Figure 1, we must have distinct ways of tracing these forces (corresponding to the solid and the dashed paths in the figure). Let's look at some distinctive properties of objects and substances that a theory of identity judgments should take into account.

Constraints on Objects Versus Constraints on Substances

An object and its substance have independent conceptual standing, according to the research we just reviewed. But what characteristics do we use to distinguish them? At a particular point in

time—say, t_i in Figure 1—an object and its material occupy exactly the same physical space. For example, a wooden chair occupies the same space as the wood that composes it. What allows us to think of them at that point as distinct beings—the chair and the wood?

One characteristic difference between objects and substances is a distinctive organization of their parts. An arbitrary portion of a quantity of wood is itself a quantity of wood, but an arbitrary portion of a chair is not usually a chair. Likewise, two quantities of wood, considered together, are a quantity of wood, but two chairs, considered together, are not a (single) chair. An entity is said to be *divisive* relative to a type if, for any part of the entity, the part is of the same type. An entity is *cumulative* (relative to a type) if any two or more entities of the same type are an entity of that type (e.g., Krifka, 2007; Pelletier & Schubert, 2003). In these terms, substances seem to be both divisive and cumulative, whereas objects are neither.⁶

Both divisiveness and cumulativeness stand in need of refinement, and we will try to fill in some details. But even our rough description makes clear that these properties are symptoms of the relative lack of structure of substances (and violations of cumulativeness and divisiveness are symptoms of the structure of objects). On intuitive grounds, the reason that a chair is neither divisive nor cumulative is that the chair must have a certain organization of its parts, and the reason that a quantity of wood is both divisive and cumulative is because it does not need to have any definite organization of parts. Some relation must unify the parts of an object, but no such relation governs substances. This distinction suggests that we might be able to use divisiveness and cumulativeness to explore the nature of this structure. We also can ask how people come to use this difference in structure in identifying objects or stuff and in generalizing properties over them.

Clarifying the nature of this substance/object difference sets the agenda for this section. We look first at proposals concerning the formal properties of substances and at the psychological evidence that bears on them. We then do the same for objects. Finally, we examine studies of how people distinguish objects from substances in identification and generalization tasks. Most of the formal properties we consider here—in particular, Principles 1 to 4 and 6 to 8—are adapted from earlier theories (e.g., cumulativeness, as a property of the reference of mass nouns, is due to Quine, 1960; divisiveness to Cheng, 1973). However, we use these characteristics as properties of the substances and objects themselves rather than as properties of the semantics of mass or count expressions. Principle 5 is a suggestion of our own, meant to clarify a crucial trait of objects. The Appendix formally relates Principle 5 to the other principles. A novel aspect of the discussion in this section is that it brings ideas from formal semantics to bear on people's beliefs about the underlying nature of objects and substances.

⁵ The possibility that both ships are the original is ruled out because it violates the transitivity of the identity relation. Call the original ship *Original*; the ship with new planks, *New*; and the ship with old planks, *Old*. If both *Original* = *Old* and *Original* = *New*, then by transitivity *Old* = *New*, but as Hobbes (1655/1839–1845) remarked, this is absurd because *Old* and *New* are distinct ships. Participants do sometimes respond *both* to problems similar to Hobbes's, but this tendency decreases if the instructions remind them to judge the numerical identity of the ships (Rips, 2011).

⁶ Other terms for *divisive* in the literature include *divided*, *dissective*, *distributive*, and *homogeneous*.

Substance structure. Substances such as water or gold depend on microphysical arrangements at the level of molecules and atoms, which are not accessible in ordinary experience. As far as people can tell in most situations, any portion of a substance is another portion of the same substance. So to measure amounts of substance, we have to impose a standard unit (e.g., cubic centimeters of water), a conventional unit (e.g., glasses of water), or a contextually available unit (puddles of water in a spill). Some of these units, which we will call *pieces*, come with constraints of their own. A puddle of water is like a lake in having spatial connectedness among its parts. The same is true of the referents of many other *pseudopartitive* phrases, such as *chunk of*, *lump of*, and *piece of* (Goddard, 2010). In general, however, substances do not have inherent units. Any spatial distribution of water is water. We can speak of a quantity of water at one time as being the same water as a quantity at another time, despite the first being a puddle and the second a scattered collection of drops. Phrases such as *quantity of water* are like *water* (and unlike *puddle of water*) in having a meaning that applies across spatially separated regions. We therefore use *quantity of N* in speaking of an arbitrary portion of a substance named by a noun *N*.⁷

Formal properties of substances. Quantities of a substance can be ordered by inclusion. For example, one quantity of juice can be part of a larger quantity. We illustrate this ordering at the left of Figure 2, where *M* is the set of all quantities of some substance. The upward pointing arrows indicate the *part-of* relation over these quantities (e.g., quantity m_1 is part of the quantity labeled $m_1 \vee m_2$). We follow convention and write $m < m'$ for the *proper part* relation: Quantity *m* is completely included in quantity *m'* but there is some part of *m'* left over. Likewise, $m \leq m'$ means that either $m < m'$ or $m = m'$.

According to current analyses in linguistic semantics (e.g., Bale & Barner, 2009; Chierchia, 2010; Gillon, 2012; Link, 1983), for any set of quantities of a substance, there is also a smallest quantity of the substance containing just these quantities as parts. This smallest containing quantity is called the *sum* of the quantities, and the sum of quantities *m* and *m'* is written $m \vee m'$. For instance in Figure 2, quantity m_1 (e.g., a particular quantity of juice) and m_2 (e.g., another quantity of juice) are both parts of the sum $m_1 \vee m_2$ (the sum of juice containing just m_1 and m_2). We can then state cumulativity in terms of sums⁸:

Principle 1: Cumulativity. If m_1, m_2, \dots, m_n are any quantities of substance *M*, then there is a smallest quantity of *M*, the sum $m_1 \vee m_2 \vee \dots \vee m_n$, of which m_1, m_2, \dots , and m_n are parts.

The sum of two quantities is not a physical operation on these quantities. It merely considers these quantities together, wherever they happen to be. The cumulativity property means that any two or more quantities of a substance, no matter where they occur, form a quantity of that substance. As we noted earlier, the same is not true for objects (e.g., two cups do not form a cup). Thus, cumulativity appears to be a distinctive feature of substances.

We also can consider a second, more debatable, principle that ensures that parts of a quantity of a substance are also quantities of that substance:

Principle 2: Divisiveness. If *m* is a quantity of *M* and *m'* is a part of *m* (i.e., $m' \leq m$), then *m'* is also a quantity of *M*.

In other words, if a quantity of a substance has a part, then that part is also of the same substance. Semantic theories differ in whether they incorporate divisiveness (cf. Chierchia, 2010; Link, 1983). Divisiveness leaves open whether a substance has smallest parts (i.e., atomic units). It asserts only that if the substance has a part, it belongs to the same type of substance. Those who reject divisiveness have in mind the possibility that substances may have parts that are too small to qualify as belonging to the same substance type. For example, the particulate theory of matter holds that substances such as water have parts (e.g., hydrogen atoms) that are not themselves water. The issue, then, is whether our ordinary concept of substances entails divisiveness, entails its opposite (substances have parts too small to qualify as that substance), or leaves it open.

As we just noted, divisiveness is compatible with the idea that substances can be decomposed only so far. Perhaps we can decompose all substances into certain particles (atomic units), but we can't further decompose them. However, if decomposition is always possible, we need a further principle to say so:

*Principle 3: Gunkiness.*⁹ If *m* is a quantity of *M*, then there is a quantity *m'* (not necessarily of *M*), such that *m'* is a proper part of *m* (i.e., $m' < m$).

Gunkiness implies that any quantity of a substance is made up of smaller parts of some substance or other. Divisiveness implies that if a substance has a part, that part belongs to the same type of substance. Principles 2 and 3 together imply that a substance will have infinitely descending chains of parts of that same substance (i.e., $m_i > m_{i-1} > m_{i-2} > \dots$, where each of these parts is of the same type).

On the one hand, divisiveness provides a clear contrast between substances and objects because it is clearly inapplicable to objects. No one believes that every part of a clock is a clock. A further point in favor of the combination of divisiveness and gunkiness is that they predict that substances have no atomic units that would allow us to count them. These principles automatically exclude such units and so explain the intuition that we cannot count the

⁷ *Quantity of N* also can have the meaning of a specific magnitude of *N*, as in "The quantity of water in the cup is 30 ml." However, we know of no better term for arbitrary portions. We therefore avoid the magnitude sense of *quantity* in the rest of this article (see Cartwright, 1970, for a discussion of the meaning of *quantity*).

⁸ The part relation and the sum relation are interdefinable: *m* is a part of *m'* if and only if the sum of *m* and *m'* is *m'* (i.e., $m \leq m'$ iff $m \vee m' = m'$). A sum also is called a *join* or *least upper bound*, and the type of structure defined here is formally a *complete join semilattice* (Davey & Priestley, 2002).

⁹ Principle 3 is not as innocent as it may seem and is the subject of debate in metaphysics and philosophy of science (for a review, see Hudson, 2007). In this literature, an item that obeys Principle 3 is called *gunk* (Lewis, 1991), and an item with no proper parts, contradicting Principle 3, is an *atom* or *simple*. Standard physical theory represents objects and space-time regions as sets of points of 0 dimension, corresponding to real numbers, and physical quantities (such as velocity) are represented as functions from these points to instantaneous values of the quantities (e.g., meters per s). These points cannot be further divided, and they therefore have no proper parts: They are the ultimate simples. But if Principle 3 is correct, then no ultimate points would exist—even points would have proper parts—and physics would stand in need of substantial revision from being pointy to being gunky (Arntzenius, 2011).

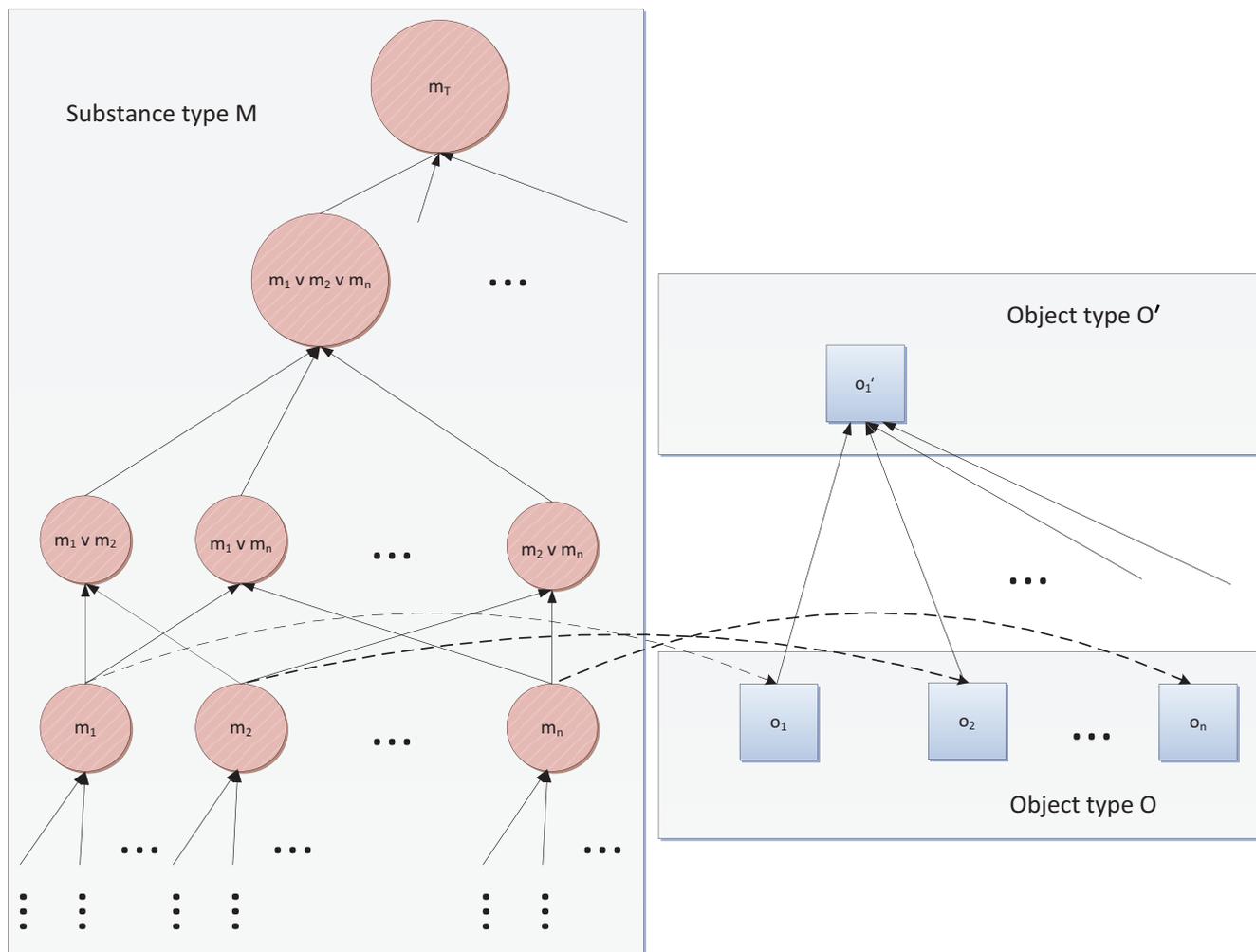


Figure 2. The organization of substance (left-hand side) and object (right-hand side) domains. Individual quantities of a substance M appear as circles, and individual objects as squares. Solid arrows connect parts of objects or substances with the wholes to which they belong. Dashed arrows connect a quantity of substance to the object that it constitutes. Horizontal or vertical ellipses (...) indicate the possible existence of other entities not explicitly shown. See the online article for the color version of this figure.

quantities of a substance in a particular amount of that substance. On the other hand, people who have learned and accepted the particulate theory of matter believe that substances do not exist in quantities smaller than the atoms or molecules that compose them. Thus, some parts of a substance (e.g., a hydrogen atom in a molecule of water) are not the same substance (water), contrary to divisiveness. Likewise, if an elementary particle, such as a quark, has no proper parts, then gunkiness is also false. If we reject divisiveness and gunkiness, though, we will need to find some other explanation for the difficulty of counting substance quantities, and we return to this point later.

We suspect that cumulateness holds for substances, but unrestricted divisiveness—in the form of Principle 2—does not. Scientifically literate adults probably think that quantities of a substance have parts that are not themselves quantities of that substance, contradicting divisiveness. They believe hydrogen is part of water but is not a quantity of water. But they recognize a limited form of divisiveness

that allows a substance to have parts of the same substance. Adults who know about elementary particles also may believe that substances do not have infinitely descending chains of parts, contradicting gunkiness, although grade school and middle school students may not necessarily share these beliefs. It is an open question whether people have an intuitive theory of chemistry that embraces divisiveness and gunkiness, which later explicit training overrules. We consider the evidence on this issue.

Empirical evidence on substances. Some data bearing on divisiveness come from a study by Au (1994, Experiment 1) with 3- to 6-year-olds. Participants saw three types of transformations: A chunk of material (e.g., wood) divided into smaller chunks, a chunk (e.g., a salt tablet) ground into a powder, or a powder (e.g., sugar) dissolved in water. Participants decided whether the transformed item “was still the same kind of stuff” as the original (or, in the case of the solution, whether it had the same kind of stuff in it). For the chunk-to-smaller-chunk and the chunk-to-powder

transformations, even the 3-year-olds correctly answered “yes” on over 90% of trials. For the powder-to-solution transformation, the proportion of “yes” answers was lower, but still comprised 60% to 85% of responses, across age groups (see, also, Rosen & Rozin, 1993). Performance was better with the latter transformation if the substance had a familiar label (e.g., *sugar*) than an unfamiliar one (e.g., *saccharin*). Younger children do less well on chunk-to-powder transformations if they do not witness the transformations but are simply told about them (Dickinson, 1987). Children’s judgments about substances, then, conform to divisiveness to at least some extent.

Of course, children who think that a ground up chunk of wood is still wood do not necessarily believe that any part of the chunk, no matter how small, is still wood. Divisiveness would commit them to the latter, more thoroughgoing belief. Nor does this evidence establish that children believe in gunkiness—that substances have no smallest parts. Evidence does exist, however, concerning one straightforward implication of gunkiness, which is that a quantity of substance is infinitely divisible. Among third to sixth grade U.S. students in one experiment, 64% thought that a quantity of Styrofoam could be divided, then divided again, and so on without end—that there would always be something left after the division (Smith, Solomon, & Carey, 2005). This percentage is about the same (67%) for eighth graders (Smith, Maclin, Grosslight, & Davis, 1997). However, these results conflict with those of seemingly similar studies. In one such study, only 27% of 7th to 12th grade Israeli students stated that it is possible to divide a quantity of water without end, and only 38% stated that it is possible to divide a copper wire without end. In the latter study, instructions to participants asked them to “Continue dividing in the same way. Will this process come to an end?” (Stavy & Tirosh, 1993, p. 580).

Participants’ willingness to respond “Something will always be left” in Smith et al.’s (2005) experiments might stem from the idea that dividing in half could never reach a point of 0 mass, and the wording of the problems would have reinforced this interpretation: “Would [the division process] ever reach a point where there was not any matter left to divide?” (p. 111). As Smith et al. (2005) remarked, the difference between the U.S. and Israeli experiments also could be due to the instructions in the U.S. studies encouraging students to ignore practical limits in dividing small quantities of a substance. As an additional possibility, Israeli students may have greater knowledge of the particulate theory of matter (or the particulate theory may easier to apply in the case of substances such as copper or water than with substances such as Styrofoam). This might lead them to think that substances such as copper have parts (e.g., electrons) that are not copper or that simply cannot be divided. But the percentage of these students who affirmed the infinite divisibility of copper wire tended to *increase* with grade (Stavy & Tirosh, 1993; Tirosh & Stavy, 1996; Tirosh, Stavy, & Cohen, 1998), which would be unexpected if students were beginning to reject gunkiness in favor of the particulate theory.

One point of uncertainty for present purposes is whether students in these studies regarded the key questions, quoted earlier, as asking about the divisibility of a particular substance (water, copper, Styrofoam) or about the divisibility of matter in general. Gunkiness predicts the infinite divisibility of matter but is non-committal about the divisibility of a particular substance. For example, gunkiness is consistent with both: (a) a quantity of water being divisible only to the level of H₂O molecules, beyond which

the parts are no longer water, and (b) the H₂O molecules being further divisible into smaller parts, which could themselves be divided into smaller parts, and so on, without end. A second open issue is whether people distinguish the possibility of infinite division of a substance from the possibility that the substance has smallest (possibly point-sized) units. Although gunkiness entails infinite divisibility (i.e., for any n , after n divisions something will be left over), the converse does not hold because infinite divisibility is compatible with point-sized atoms. For example, consider a line segment. Although the segment is infinitely divisible into halves, then fourths, then eighths, and so on without end, the segment may still have points as its smallest units, which cannot be further divided.

Summary of substance structure. Our goal is to give a general account of how people—including scientifically illiterate children—think of substances. So we should not presuppose that the particulate theory is built into their concepts (Schaffer, 2003; Zimmerman, 1995). But neither should we assume (along the lines of Principles 2 and 3) that a particulate theory is off limits for them. Grade school children clearly have difficulties learning the particulate theory (e.g., Novick & Nussbaum, 1978, 1981; Taber & García-Franco, 2010), although they seem better able to appreciate that liquids and gases are composed of particles than that solids are (Nakhleh & Samarapungavan, 1999). By the end of high school, however, nearly all students believe that matter is composed of atoms (Harrison & Treagust, 1996). We therefore take cumulateness and a limited form of divisiveness as characteristics of people’s beliefs about substances. For the same reason, we assume that neither gunkiness nor its negation (i.e., some quantities of a substance have no proper parts) is a necessary characteristic of people’s thinking about substances.

Still, cumulateness and limited divisiveness are probably enough to explain the intuition, mentioned earlier, that we cannot count the quantities of a substance (e.g., the number of quantities of wood in a wooden chair). Because two quantities of a substance at one level (e.g., quantities m_1 and m_2 in Figure 2) sum to form a single quantity at another ($m_1 \vee m_2$ in the figure), counting runs into ambiguities at the start. Suppose, for example, that a glass of wine spills into four puddles. Should we count this as one quantity (the entire spilled amount), four quantities (the number of puddles), five quantities (the entire amount plus the number of puddles), or some other number?

Object structure. Unlike substances, objects are not cumulative in the sense of Principle 1. Two or more chairs are not ordinarily parts of a single chair, and two or more horses are not parts of a single horse. Likewise, single objects are not divisible in the sense of Principle 2 because parts of an object such as a chair are not themselves chairs. Cumulateness and divisiveness are probably false, not just of objects of a particular kind, but of objects in general. We do not conceive of two arbitrary objects (e.g., a horse and a chair) as forming a single object of any type.

Semanticists have pointed out a parallel between the cumulateness of substances and the cumulateness of plural objects (e.g., Link, 1983): Two or more horses are parts of a single plurality of horses. But our interest here centers on single objects rather than on pluralities. For the same reason, we will not discuss other object groupings that do not compose a single object. People can conceptually group several objects and think of the resulting group as a single unit or *chunk* (Miller, 1956). For example, chess

masters can remember a meaningful board position consisting of multiple chess pieces as an individual chunk and recognize it as such on later encounters (Chase & Simon, 1973). The pieces are related to the chunk as parts to a whole. However, we do not usually take a chunk to be an individual object. The chess pieces in their arrangement do not form a single object on a par with an individual rook. The same is true of collections (Markman, 1989), such as forests, armies, and families because we do not consider these items as objects in the same way we do the trees, soldiers, and family members that form their parts. Important as these groupings are, our focus here will be on the composition of objects.

The right-hand side of Figure 2 illustrates the constraints on objects' parts and wholes. Here, several objects of type O — o_1, o_2, \dots, o_n —together with objects of other types, combine to form an object of a different type O' . Several wooden table legs (members of type O), for example, together with a tabletop, can form a table (a member of O'). However, nothing guarantees the existence of objects that are arbitrary wholes and parts of other objects in the way cumulateness and divisiveness do. A few exceptions exist to objects' typical resistance to cumulateness and divisiveness. A famous example is the triple crown of the Pope, composed of three interconnected crowns, and modern designers have produced chairs from nested chairs and tables from nested tables. In general, though, objects of a particular type have smallest units of that type. We can decompose the Pope's crown, for example, into crowns that have no crowns as parts. Although objects may be parts of objects of other types and may have parts of their own, the combinatorial possibilities are much more limited than for those of substances. Objects are *stratified* in a way that substances are not: A part of an object of a given type (e.g., a part of a table or of a horse) usually is not an object of the same type, and a sum of two or more objects of a given type is usually not in that type. Figure 2 illustrates stratification by placing the objects of one type (e.g., table legs) in one rectangle on the right-hand side, and the combined object (e.g., a table) in another.

Figure 2 adopts the idea that objects and substances belong to separate conceptual domains, indicated in the right- versus left-halves of the figure. However, a given quantity of substance (e.g., a quantity of wood) can constitute an object (e.g., a table leg), and dashed arrows in Figure 2 illustrate this relationship. For example, the substance quantity m_1 constitutes the object o_1 . (Figure 2 shows the simplest case in which all objects of type O are made of substance M , but in general, objects can be made from more than one substance type.) In the rest of this article, we will distinguish *composition* (parts composing a whole within a single realm, solid arrows in Figure 2) from *constitution* (matter constituting an object, dashed arrows). This two-domain view accords with some semantic (e.g., Link, 1983) and psychological (e.g., Keil, 1979) theories, though other options are possible (see Chierchia, 2010, for an alternative). We stick with the two-domain view here as a working hypothesis to see how well it accords with the empirical evidence.¹⁰

Formal properties of objects. One way to capture the nature of objects is to think of them as composed of atomic units. As a general formulation of this idea, we can consider Principle 4:

Principle 4: Atomism: If o is an object, then o can be completely decomposed into a set of objects S , none of which has

a proper part of its own (i.e., if o' is in S , then there is no o'' such that $o'' < o'$).

Principle 4 says that objects bottom out at the level of atoms, which have no proper parts (see the Appendix for a definition of *completely decomposed*). Thus, atomism is the opposite of gunkiness in prohibiting infinitely descending chains of objects, but it is consistent with finite chains, for example, crowns made up of smaller crowns.

More crucial to object concepts, however, is the fact that we think of most objects of a given type as having smallest units of that type. To represent this fact, we need to relativize Principle 4 to specific types of objects:

Principle 5: Stratification: If o is an object of type O , then o can be completely decomposed into a set of objects S , none of which has a proper part of type O (i.e., if o' is in S , then there is no o'' such that o'' is an O and $o'' < o'$).

The Appendix gives some formal relations between stratification and the earlier substance principles.

Stratification squeezes objects within a given type so they cannot freely decompose into objects of the same type. For example, dogs cannot be decomposed into smaller dogs. The principle leaves open what qualifies as a "type of object," but we can assume that these types include everyday categories of physical objects, such as dogs and doorbells. In the usual case, o will itself provide the decomposition that stratification calls for because most objects do not have proper parts of the same type (e.g., doorbells do not have doorbells as parts). In Figure 2, for example, object o' has no proper parts of the same type. But stratification still leaves open the possibility of nesting (e.g., crowns made up of crowns) as long as the nesting comes to an end (a level of smallest crowns that have no crowns as proper parts). For this reason, stratification does not completely exclude the possibility of ambiguities in counting objects of a given type. In counting the Pope's crowns, we could count the largest crown, the three smaller ones, or some combination. The object principles nevertheless limit these ambiguities, whereas the substance principles promote them.

Empirical evidence on objects. Although adults follow stratification in their conception of most objects, the correct application of this principle appears surprisingly late in development. Shipley and Shepperson (1990) first showed that 3- and 4-year-olds incorrectly counted the detached parts of members of common categories as if they were full-fledged members of those categories. On one trial, for example, children saw three whole forks and an additional fork split into two clearly separated pieces. When asked, "Can you count the forks?" most children responded that there were five, including each piece in their count. In fact, they responded in the same way to "Can you count the forks?" as to "Can you count the things?" ignoring the information provided by *forks*. Responses of this sort occur, not just in explicit counting tasks, but

¹⁰ In suggesting that objects and substances comprise distinct domains, we are claiming that the entities within them obey different structural principles (e.g., cumulateness) that we hope to pin down. We use *domain* in a broad sense in which even noncausal realms, such as language and mathematics, comprise domains, and this usage has precedents in earlier theories both in psychology (e.g., Carey & Spelke, 1994) and in linguistics (e.g., Chomsky, 1980).

also those involving comparison (“Who has more forks?”) and quantifiers (“Can you touch every fork?”), as Brooks, Pogue, and Barner (2011) demonstrated.

Recent research has found some limits to children’s confusion about split objects. Even 3-year-olds are able to give separate correct counts to whole animals and to their undetached familiar parts. “Can you count the animals?” and “Can you count the feet?” both get accurate counts (Giralt & Bloom, 2000). Likewise, 4-year-olds do not count familiar detached parts when asked to count wholes (Brooks et al., 2011). For example, they do not include detached wheels of a bike when they count bikes. So children’s difficulties seem restricted to cases in which they have to decide whether arbitrary detached elements should be included in their computation. When the elements are less arbitrary—for example, when the elements have their own names or when the elements appear object like in their own right (see Identifying Objects Versus Substances later in this article)—children are less likely to include them in their counts of whole objects (Srinivasan, Chestnut, Li, & Barner, 2013). Making the partitive phrase *piece of* salient by asking children to choose, for example, between whether an object is a “piece of fork” or “a fork” also decreases counting errors (Srinivasan et al., 2013; but see Sophian & Kailihiwa, 1998).

You can put yourself in the children’s place if you imagine being asked to count instances of *unarticulated* objects, such as sticks, clouds, or icebergs. The experimenter presents you with three 12-in. sticks and two 6-in. sticks, and asks, “Can you count the sticks?” Adults would presumably reply that there are five sticks, even if they had evidence that the experimenter had created the 6-in. items by breaking a 12-in. stick in half. Children’s responses to articulated objects, such as forks, shoes, and bikes, follow the same pattern, but are subject to the limits just discussed. In other words: (a) both children and adults count detached parts of unarticulated objects as instances of the same object type (e.g., detached stick parts are sticks); (b) neither children nor adults count detached parts of articulated objects as objects of the same type if these parts are object-like in their own right and belong to a different object kind (e.g., detached bike wheels are not bikes); but (c) children and not adults count detached parts of articulated objects as instances of those objects if the parts are not object like (e.g., arbitrary detached parts of bikes are counted as bikes by children but not by adults). For articulated objects, then, children

know not to count parts that belong to different kinds but do not generalize this prohibition to arbitrary parts of the same objects.

In thinking about these results, we should bear in mind that detached parts of objects are no longer actually parts of those objects. For example, a detached bike wheel is no longer a part of the bike from which it has been removed. It qualifies as a part only in the sense of being a former part or a typical part of a bike. For that reason, stratification does not directly apply to detached parts. A missing piece of the puzzle is whether children consider arbitrary undetached parts of an object as an object of the same type. Do preschoolers regard an undetached but arbitrary section of a bike’s frame as a bike? If that is the case, they believe that some parts of a bike (e.g., the wheels) are not bikes, whereas other parts are (e.g., the arbitrary frame section). Such children (if any) do not know how to do the decomposition that stratification calls for.

Summary. The principles we have considered so far provide a rough classification of object and substance entities. Table 1 collects the different sorts of entities we have discussed and indicates whether a principle is typically true of the entities (+), is typically false (–), or is neither typically true nor false (0). These types (substances, pieces, unarticulated objects, and articulated objects) are not necessarily exhaustive, but they illustrate the range of variation in our concepts. (The table omits gunkiness and atomism because these two principles are not part of everyone’s concepts of objects or substances, as we argued.)

Cumulativeness distinguishes substances from the other entities because only substances guarantee that any two substance quantities combine to form another substance quantity. At the opposite end of the spectrum, stratification picks out articulated objects because these items generally have no parts of the same type (or have only a limited number of such parts). Unarticulated objects also seem to obey stratification in that undetached parts of such objects probably do not count as instances of the type of their whole. An undetached part of a stick is probably not a stick on its own. It becomes one only when detached in which case it is no longer part of the original (though the question mark in the table indicates an element of uncertainty about this judgment). Much the same seems true of pieces, such as lumps of clay. As we are about to discuss, objects, including unarticulated ones, have to meet relational constraints that limit decomposition. In the case of substances, however, stratification depends on a person’s beliefs about the physics of matter. For example, whether you think gold

Table 1
Summary of the Application of Three Principles to Some Common Entity Types

Entity	Cumulativeness ^a	Divisiveness ^b	Stratification ^b
Substances (e.g., water, air, clay, wood)	+	0	0
Pieces (e.g., bodies of air, lumps of clay, hunks of wood)	–?	–?	+?
Unarticulated objects (e.g., sticks, clouds, icebergs)	–	–?	+
Articulated objects (e.g., dogs, tables)	–	–	+

Note. Cumulativeness = any two entities of type T form an entity of type T; divisiveness = any part of an entity of type T is an entity of type T; stratification = any entity of type T can be completely decomposed into entities, none of which have entities of type T as parts; plus (+) = principle is typically true of the entity type; 0 = principle is neither typically true nor false; minus (–) = principle is typically false.

^a Cumulativeness applies to entities regardless of location. A type of entity is cumulative if even spatially separated instances are instances of the same type. ^b Divisiveness and stratification apply only to current parts of an entity. Thus, detached legs of tables or detached sections of a stick do not qualify as parts of these entities for purposes of the principles.

can be completely decomposed depends on whether you know about gold atoms, and we leave this undecided for purposes of describing laypeople's substance concepts. The considerations here are similar to those we discussed for divisiveness (see Formal Properties of Substances): Divisiveness does not apply to gold if you know that gold has subatomic parts that are not gold. (See the Appendix for the relation between stratification and divisiveness.)

The question marks in the table point to pieces and unarticulated objects as potentially intermediate between clear substance and clear (articulated) object concepts. Items in these categories lack proper parts whose type is clearly different from that of their whole. This intermediate status will become important later in understanding the way substances constitute objects.

Further object and substance principles. Two additional principles about objects and substances seem parts of people's intuitive view. The first of these is Leibniz's Law or the Indiscernibility of Identicals.

Principle 6: Leibniz's Law: If e and e' are entities (objects or quantities of substances) and $e = e'$, then for any property P , e has P if and only if e' has P .

According to Leibniz's Law, identical entities share all their properties. This principle follows from the fact that identity is the relation that an entity has to itself and to nothing else. How could an entity have a property without sharing it with itself?

The second principle is the familiar idea that no two things can simultaneously appear in exactly the same place.

Principle 7: Anticoincidence for Objects: If $o \neq o'$, then objects o and o' cannot occupy exactly the same place at the same time.

Principle 8: Anticoincidence for Substances: If $m \neq m'$, then substances m and m' cannot occupy exactly the same place at the same time.

Evidence from studies of infants, to be discussed later (see Origins of Object and Substance Concepts), suggests that Principle 7 is in place in the first few months of life (e.g., Baillargeon, 1995; Hespos & Baillargeon, 2001; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wilcox & Baillargeon, 1998).

Constraints on objects. What is responsible for the limits on what can be an object—the constraints inherent in stratification? One hypothesis is that an ordinary physical object requires some relation among its parts (e.g., Fine, 1999). However, not every relation will do (as, e.g., Koslicki, 2008, argued). Mount Rushmore and Mitt Romney are related by the facts that Mount Rushmore is heavier than Romney, is older than Romney, is less likely to be a political candidate, is more likely to be featured on a list of U.S. monuments, and shares the same initials. But none of these relations unites Romney and Mount Rushmore into a single object. Prototypical objects such as horses and toasters have parts that are spatially connected. According to Spelke's (1990) boundedness principle, if a path of surface points connects two points, then the points belong to the same object. However, spatial connection is not sufficient for objecthood. Two people do not become a single object when they shake hands (van Inwagen, 1987). In a similar way, Spelke's cohesion principle states that if two points are on the same object, then a path of surface points connects them. But

spatial connection is not always necessary. We sometimes recognize as objects combinations of parts that are spatially disconnected. We allow the state of Michigan or the United States to be a single object because of the political connection among its parts, a solar system or a galaxy because of a causal connection among its parts, and a two-piece bathing suit or a (wirelessly connected) desktop computer because of a functional connection among its parts.

We can think of an object as composed of its parts together with a relation of unity and organization that holds among the parts. Objects in this respect are similar to schemata or frames—a relationship that is quite clear in schema-based descriptions of objects, such as faces (Rumelhart, 1980), cubes, and rooms (Minsky, 1975). (Some theories of perceptual object recognition—e.g., Biederman's, 1987, recognition-by-components theory—also rely on relations among parts.) A particular chair, for example, has a parts list containing four legs, two arms, a back, and a seat; and it has a unity-and-organization relation in which the legs support the seat, the seat supports the arms, the back is attached vertically to the seat, and so on. The parts list and the unity-and-organization principle do not provide a definition of chair: Many chairs do not have arms, for example, and an individual chair can sometimes survive the loss of a part. However, the list and principle describe the structure of a particular chair at a time.

The distinction between an object's parts list and its unity-and-organization principle helps explain the difference between objects and substances: Substances do not require unity-and-organization. This allows substances to combine freely in the way that the cumulateness principle sanctions. But we are still left with the problem of which relations produce everyday objects and which do not. As we just noticed, not all ways of uniting a set of parts produces an object (e.g., spatial connectivity is not always sufficient) and spelling out the nature of the unity-and-organization relation in a nonquestion-begging way is difficult. The temptation is to see the unity-and-organization principle as whatever it is that makes something an object, and this is not helpful if our aim to explain how objects differ from substances.

One potential way to ground the unity claim is to suppose that an object inherits its unity-and-organization principle from the kind of object to which it belongs. According to this possibility, a chair, for example, has the structure it does because it belongs to the kind chair, which specifies this structure. This theory is consistent with the fact that the structure of one type of object (e.g., chairs) often differs from that of other types (e.g., cell phones). Likewise, the difference in type between an object and its parts encourages the idea that the distinction among types is important to the object's structure. However, this approach suffers from problems that are similar to those of classical theories of concepts (see, e.g., Fodor, 1998; Murphy, 2002; Smith & Medin, 1981). Neither experts nor novices seem able to give informative sets of parts and relations that are necessary and sufficient for ordinary types of objects, such as chairs or horses (e.g., Rosch & Mervis, 1975), and a reasonable explanation for this inability is that no such sets exist. Which relation among chair parts is common to all chairs (including beanbag chairs and hanging chairs)? We also seem able to identify objects even when we are unable to classify them—for example, in recognizing an unknown object at a distance or a novel object washed up on a beach. Category-level

information is probably neither necessary nor sufficient for determining objecthood, but then what restricts the relations that can play the unity-and-organization role? This issue is known as the *special composition question* (van Inwagen, 1987), and we may be able to gather hints about these restrictions by studying the cues people use to decide whether something is an object versus a substance. (For further discussion of the role of kinds and our own attempt to make good on the unity-and-organization principle, see the section A Hypothesis about Object/Substance Differences: Shaping later in this article.)

Identifying objects versus substances. One way to find out how people distinguish objects from substances is to vary the properties of an unfamiliar item and ask people how they would refer to it. For example, Prasada, Ferenz, and Haskell (2002) had participants inspect an unfamiliar but regularly shaped piece of material (e.g., cardboard) or an irregularly shaped piece of the same material. In each case, the participants decided whether to describe the scene using the sentence *There is a blicket* [or other nonsense noun] *in the tray* or *There is blicket in the tray*. On the assumption that count nouns (*a blicket*) are likely to name objects and mass nouns (*blicket*) to name substances, participants' choices indicated whether regularity of shape is a cue for objecthood.¹¹ Additional experiments tested whether seeing repeated instances of the same (irregular) shape and seeing an item perform a function in virtue of its shape also would increase the choice of count-noun descriptions. Middleton, Wisniewski, Trindel, and Imai (2004) used a similar procedure, displaying a pile of coarse sugar crystals and asking participants to circle a count-noun phrase (*We call these blickets*) or a mass-noun phrase (*We call this blicket*) that best described it. Participants either interacted with the individual crystals (dropping them one-by-one through a hole) or merely observed the pile. In a further experiment, participants saw pictures of similarly shaped items either spaced apart or clustered together. All these variables—regularity of shape, repetition of shape, shape-dependent function, and discreteness of individual elements—were effective in getting participants to refer to the item with a count noun. Prasada et al. argued that these cues increased the likelihood that people would see the item as having nonarbitrary structure, which in turn would lead them to adopt an “object construal” of the item.

As an additional cue to objecthood, we can add the solidity of an item. Hall (1996) asked 4-year-olds and adults to name forms (e.g., squares or circles) made from solid material (e.g., wood) or non-solid material (peanut butter). Both age groups tended to name solids with phrases related to objects (usually with a count-noun phrase) and to name nonsolids with phrases related to substance (with mass nouns). For example, they tended to call a square piece of wood *a square*, but a square piece of peanut butter was *peanut butter*.

Of course, substances can be either solid or non-solid; so the preferences expressed in Hall's (1996), Middleton et al.'s (2004), and Prasada et al.'s (2002) experiments can be overruled. People can name the substance (e.g., brass) that makes up a solid object (see Evidence About Constitution, later in this article), but they prefer to use a count noun in answering the question “What is that?” with respect to the item. Along the same lines, people can sometimes name the substance that makes up a regularly shaped or repetitively shaped item, but they nevertheless prefer to describe the item using a count noun rather than a mass noun. The link

between count nouns and objects (and between mass nouns and substances) is not a simple one-to-one connection (e.g., Pelletier, 2012). But granting the connection for the moment, solidity, discreteness, regularity of shape, repetition of shape, and shape-dependent functioning all seem to draw people's attention toward an item's status as an object, whereas nonsolidity, continuousness, irregularity or uniqueness of shape, and lack of an obvious shape-dependent function all hint at its status as stuff.

Generalizing over objects versus substances. Similar conclusions about the difference between objects and substances come from studies in which people must generalize membership in a category from sample items. In these experiments, participants learn a nonsense label for an unfamiliar standard item (e.g., *This is my blicket*) and must then decide which of a pair of related target items has the same label (*Point to the blicket*). For example, the experimenter may label as *my blicket* a plumber's brass tee fitting, and participants have to decide whether the referent of *the blicket* in the target pair is (a) a plastic tee fitting or (b) three irregular pieces of brass (Dickinson, 1988; Soja, Carey, & Spelke, 1991). The rationale is that choice of the plastic tee is evidence that the participant has understood *my blicket* as referring to an object (an instance of the object category blickets), and choice of the irregular brass pieces is evidence that the participant has understood *my blicket* as referring to a substance (a quantity of the substance blicket). One advantage of this procedure is that it does not have to rely on the mass/count distinction to tap people's intuitions about objects and substances. *My blicket* and *the blicket* in the phrases just quoted are neutral with respect to mass/count syntax.

Dickinson's (1988) and Soja et al.'s (1991) original experiments tested children with standard items that were either solid objects, such as the tee fitting, or nonsolid items, such as a blob of sawdust. In the latter case, the test trials pitted (a) a similarly shaped blob of another material (e.g., orzo) against (b) three differently shaped portions of the same material (sawdust). Thus, for both solid and nonsolid standards, participants chose between:

Shape alternative: An item with the same shape (and number) as the original but different material.

Material alternative: An item with the same material but different shape (and number).

The results showed generalization by shape and number for the solid standards (i.e., participants selected the Shape alternative), but generalization by material for the nonsolid standards (participants selected the Material alternative). Soja et al. (1991) concluded that the children understood the solids as countable objects of a particular type, whereas they understood the nonsolids as portions of substances of a particular type. In terms of Figure 2, solidity selected an object in the right half of the diagram and restricted generalization to a single object of the same type (e.g., from o_1 to o_2). Nonsolidity selected a quantity in the left half of the diagram and limited generalization to portions of the same type (e.g., from m_1 to m_2 , or from

¹¹ Prasada et al. (2002) also used the phrase *There is a piece of blicket in the tray* in place of *There is blicket in the tray*, with little change in the results. See also Li et al. (2009, Experiment 3) who asked participants to rate directly the likelihood of an item being an object versus a substance and found effects of solidity and shape-dependent function.

m_1 to $m_2 \vee m_n$). These findings are consistent with the possibility that children are attributing substance principles, such as cumulateness and divisiveness, to the nonsolid item, and object principles, such as stratification, to the solid item.

Subsequent experiments using similar methods (e.g., Gathercole & Min, 1997; Imai & Gentner, 1997; Imai & Mazuka, 2007; Li, Dunham, & Carey, 2009; Lucy & Gaskins, 2003; Soja, 1992; Subrahmanyam, Landau, & Gelman, 1999) confirm that participants (2-year-olds to adults) generalize by shape from solid objects, even when the number of objects in the Shape and Material alternatives is constant (i.e., when the parenthesized material is omitted in the statement of these alternatives, above). Figure 3 summarizes the results from some of these studies that used comparable methodologies.¹² The figure presents the data from English speakers for the two extreme age groups: adults in Panel a and 2-year-olds in Panel b. The *x*-axes divide the standard stimuli from these studies into complex solids (e.g., a plumber's brass tee fitting), simple solids (e.g., a kidney-shaped wad of wax), complex nonsolids (e.g., a Γ -shaped blob of shaving cream), and in the case of the 2-year-old data, simple nonsolids (e.g., a smear of frosting). The *y*-axis gives the proportion of same-shape choices. Although the data show considerable variation across studies, especially for simple solids and complex nonsolids, the trend is clear for both age groups: Participants are more likely to generalize by shape (choose the Shape alternative over the Material alternative) for solid standards than for nonsolid standards. The results do not seem to depend on whether the experimenter labels the standard explicitly (*This is my blicket; point to the blicket*) or only implicitly (*Look at this; which is the same?*). Solid lines in the figure indicate the former instructions, and dashed lines indicate the latter. (The dashed line for the 2-year-olds is the average of the two types of instruction from Li et al., 2009, which did not differ statistically.)

The one obvious exception to the decreasing trend comes from Li et al. (2009, Experiment 2) who equated their standards according to ratings of "the degree to which the function of the item would depend on its overall shape and outline." For standards whose shapes had little functional relevance—highly amorphous items—participants' choices were near chance for complex solids, simple solids, and nonsolids alike. The formlessness of these standards hints that participants' same-shape choices in other experiments may depend on the items having nonarbitrary (e.g., function-driven) structure, in accord with Prasada et al.'s (2002) hypothesis, mentioned in the preceding section.

Of course, nonsolids are more likely to lose their shape than solids, and shape may therefore not be a salient property of the nonsolid standards. If so, participants' generalization from those standards may reflect their attention to the items' remaining properties, such as texture and color, without their having to conceive of these items explicitly as substances. Colunga and Smith (2005) presented a connectionist simulation that is able to learn the associations between solidity, shape, and materials that are inherent in the entities named by children's earliest nouns. The simulation learns, in particular, that in noun categories containing solid exemplars, the exemplars tend to have similar shape (but different materials), whereas in noun categories containing nonsolid exemplars, the exemplars tend to have similar materials (but different shapes). For example, *table* refers to a category of similarly shaped items of varied material, but *milk* refers to a category of homogeneous material of different shapes. After training on several of

these categories, the network was able to generalize in the way children do: from a solid standard to the Shape alternative and from a nonsolid standard to the Material alternative.

Colunga and Smith's (2005) results suggest that people's performance in the generalization task may reflect their knowledge of correlations within common categories: Categories of solid items have stable shapes, but categories of nonsolid items have stable materials. A deflationary view of knowledge of objects and substances might stop there. Perhaps all there is to this knowledge is recognition of these associations. Objects comprise the solid, shape-based categories; substances the nonsolid, materials-based categories. However, difficulties for this point of view come from exceptions to these relationships. We know, at least as adults, that object categories can include things such as soufflés and jellyfish that are not solid, and substance categories can include material like silver and wood that are solid. Equally important, these correlations do not explain principles, such as cumulateness and stratification, that seem central parts of our ideas of what makes something an object or substance. Still, the success of the simulation shows that understanding these deeper principles may not be necessary for correct performance in the generalization task. As Colunga and Smith pointed out, limitations exist on how much the generalization experiments can tell us about the object/substance distinction.

Generalizing from objects versus substances. The experiments of Figure 3 (those indicated by solid lines) asked participants to generalize membership in a novel category (e.g., *blickets*) from one exemplar (the standard item) to another (one of the target items). The same is arguably true when participants have to decide which of the target items is "the same" as the standard because *the same* in this context means same type (in the experiments indicated by dashed lines). However, we also can ask whether properties true of one item generalize to other items by virtue of shared substance or shared object type. For example, adults know that chemical and physical properties, such as burning with a green flame or conducting electricity, generalize from one sample of a substance to another (Nisbett, Krantz, Jepson, & Kunda, 1983). Other properties, however, generalize by object type. Learning that a wooden spoon can hold liquid makes it likely that a metal spoon (but not a wooden pencil) can hold liquid. Au (1994) and Kalish and Gelman (1992) showed that by 4 years of age children distinguish these two patterns. Told that a plastic bowl is used for chafing, children chose a glass bowl over a plastic hairbrush as the item that is also used for chafing. But told that the plastic bowl will get soluble when put in acid, they chose the plastic hairbrush over the glass bowl as the one that will also get soluble (Kalish & Gelman, 1992). Children apparently realize that they should project functional properties (what an item is used for) by object type, whereas they should project

¹² The experiments in Figure 3 are drawn from those obtained by searching PsychInfo with the keywords *substance* and *noun* and the keywords *mass* and *noun*. We have omitted from Figure 3 experiments that did not test either adults or 2-year-olds (e.g., Dickinson, 1988; Gathercole & Min, 1997), experiments that asked participants to label a single entity explicitly using a mass or count noun rather than to point to one of two target entities (e.g., Hall, 1996; Middleton et al., 2004; Prasada et al., 2002), and experiments that labeled the standard object with a mass or count noun (e.g., *this is a blicket; this is blicket*; e.g., Soja, 1992; Subrahmanyam et al., 1999).

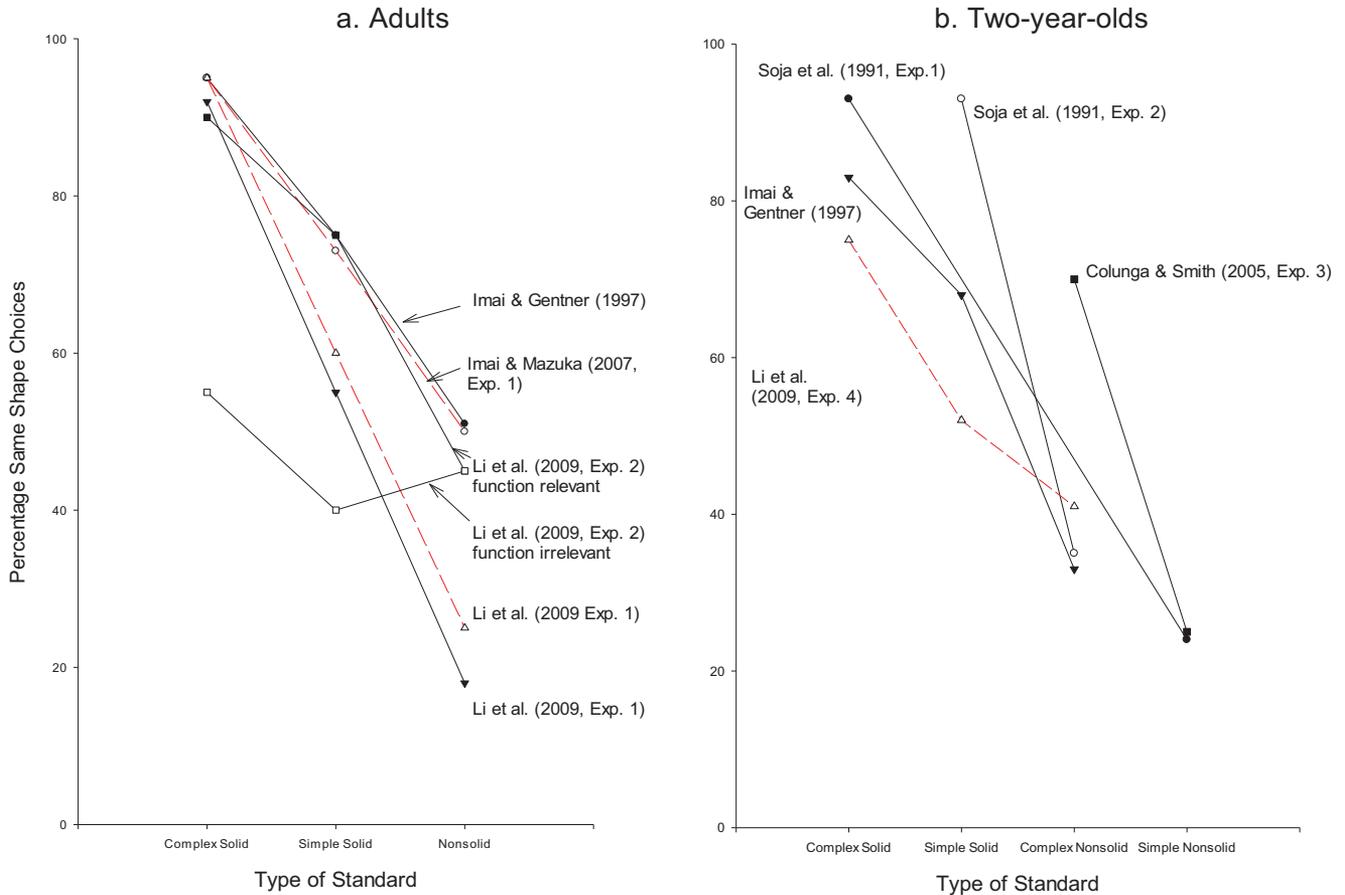


Figure 3. Summary of results from studies of how adults (Panel a) and 2-year-old children (Panel b) generalize from objects of different types (complex solids, simple solids, complex nonsolids, or simple nonsolids) to a second object with the same shape (in preference to a second object with the same substance). See Footnote 12 for exclusions from these experiments. Sourced from Colunga and Smith (2005); Imai and Gentner (1997); Imai and Mazuka (2007); Li, Dunham, and Carey (2009); Soja, Carey, and Spelke (1991). See the online article for the color version of this figure.

properties based on physical interaction with other materials by substance type. Before about 3 years of age, however, children seem to have difficulty correctly generalizing even familiar properties of solid substances, such as bendability (Prasada, 1993).

Summary. Ordinary physical objects come with restrictions on their structure, restrictions that do not apply to substances. Cumulateness implies that two or more quantities of a substance form a quantity of the same substance. But stratification means that two or more objects of a particular type do not usually form an object of the same type (see Table 1). Objects require a relation of unity-and-organization among their parts that puts free combinations off limits. People find evidence of this relational structure in the solidity and discreteness of an entity, the repetition of its shape, and the suitability of the shape for certain functions. These cues make it likely that people will refer to the entity with a count noun phrase (Hall, 1996; Middleton et al., 2004; Prasada et al., 2002) and will classify it explicitly as an object (Li et al., 2009). Solidity and shape-dependent function also increase the probability that people will project the entity's category to items with the same

shape rather than to items with the same material, giving rise to the data pattern in Figure 3.

Constitution of objects by substance

The common sense picture of objects and substances that we have been developing in Figures 1 and 2 implies a puzzling relation between these two domains. In Figure 1, for example, material m completely makes up object o at time t_p , and in Figure 2, the dashed lines connect individual portions of matter to objects they completely constitute. How do we understand the nature of constitution? This question is a fundamental issue in metaphysics, but one that has attracted little attention from psychologists. In this section, we sketch the conceptual difficulties that constitution produces and then review the scant psychological evidence relevant to it. (For reviews of the debate in metaphysics, see Johnston, 2005; Paul, 2010; Rea, 1997.)

Problems of constitution. We have been thinking of objects and substances as inhabiting two different ontological domains interrelated by constitution. For example, m_1 in Figure 2 is a

quantity of some substance M that constitutes an object o_1 . According to this picture, not all quantities of a substance constitute an object, but certainly, some quantities do. A particular quantity of gold, for instance, might constitute a gold ring. In the reverse direction, all physical objects are constituted by some substance or substances; so far, so good.

Difficulties begin, however, if we take a substance quantity as constituting more than one object. We can conceive of the quantity of gold in a ring as a particular lump of gold. This lump of gold would seem to be distinct from the ring because they have different properties. Let us suppose, as seems reasonable, that the lump existed before a jeweler fashioned it into a ring and will exist after she reshapes the ring to form a clasp. Then the lump and the ring have different histories, and by Principle 6, Leibniz's Law, they are different objects. Likewise, the ring may be ornate, old-fashioned, and have artistic value, but the lump may have none of these properties. Thus, we seem to have a case in which the same quantity of matter simultaneously constitutes two distinct objects, the ring and the lump. The trouble is that during the time the ring exists, the lump of gold and the ring are in exactly the same locations, violating Principle 7, anticoincidence for objects, which states that this situation is impossible: Two different objects cannot be in the same place at the same time. (For other variations on this problem, see Rea, 1997; Sattig, 2010.)

A number of solutions are on offer for this problem about constitution, including some quite radical ones that deny the existence of ordinary objects such as rings (e.g., O'Leary-Hawthorne & Cortens, 1995). Whatever attractions these nihilist and revisionist solutions have in metaphysics, they are not helpful for our own goal, which is to understand everyday concepts of substances and objects. A more interesting possibility, though, is a kind of partial nihilism that recognizes rings but denies that entities such as lumps of gold or chunks of wood are objects. On its own, a lump of gold is what we called a piece in Table 1 and has uncertain status as an object. Perhaps a lump of gold is no more than a quantity of the substance gold; it's an entity such as m_1 in the left-hand substance domain in Figure 2. If so, our impression that a lump of gold is an object may just be an understandable error, a confusion between a quantity of matter like m_1 and an object like o_1 . Assuming this is correct, we can avoid the unpleasant contradiction between Leibniz's Law and anticoincidence for objects. Because the lump of gold is not an object, it can be in the same place at the same time as the ring it constitutes. Ditto for a chunk of wood and the chair it constitutes or a lump of clay and the statue it constitutes, to cite other examples from work on this topic (see Burke, 1994, who sympathetically considers but rejects this possibility).

But although this quasi-nihilist approach seems to fit the ideas about substances and objects that we have been developing, it meets with some difficulties. On what grounds can we admit rings but not lumps of gold into the domain of objects? Moreover, not all of the problematic examples involve entities like lumps or chunks that we can write off as mere quantities of matter. Intuitively, a piece of paper seems to be a genuine object, but it produces the same puzzle about constitution if someone folds it into a paper airplane (Sattig, 2010).¹³

If we recognize as objects lumps of gold, chunks of wood, pieces of paper, and other such entities, then the conflict between Leibniz's Law and anticoincidence becomes pressing. One possi-

ble resolution is to retain anticoincidence for objects and to restrict Leibniz's Law in such a way as to permit the lump and the ring to be identical. The lump and the ring may be the same object, but described from two different points of view—as a lump or as a ring—with properties that are distinctive to these two levels of description. Described as a ring, the object may have artistic value; but described as a lump of gold, the object may have no value apart from its market price per ounce. According to this *one-object* theory, this difference in properties, though, is not of the sort that would dictate a difference in objects but only a difference of perspective.

However, a difficulty with one-object solutions is that they do not easily accommodate the intuition that before the jeweler shaped the ring, the lump existed but the ring did not. The existence of an object at a time does not seem just a matter of the perspective we take on it. It is odd to think that the putatively single object in question both existed (when described as a lump) and did not exist (when described as a ring). (For further difficulties with the one-object theory, see Fine, 2003; Johnston, 1992).

Another possible solution to the problem of constitution is to maintain that the lump of gold and the ring are nonidentical, treating anticoincidence for objects as a mistake. Sometimes distinct objects can be in the same place at the same time (for positions of this sort, see Baker, 2007; Fine, 2003; Johnston, 1992, 2006; Wiggins, 1968). This two-object solution has to contend with the experimental findings on infants (Baillargeon, 1995; Hespos & Baillargeon, 2001; Spelke et al., 1992; Wilcox & Baillargeon, 1998), which we discuss later, and with a strong intuition that favors anticoincidence in ordinary cases. For example, if the gold ring in our example is on Calvin's finger, you might find it odd if we claimed that there are two objects on his finger—the lump of gold and the ring. Likewise, if the lump of gold weighs 3 oz, then the ring also weighs 3 oz. So taking the lump and the ring to be distinct objects seems to imply incorrectly that what's on Calvin's finger weighs 6 oz.

However, we may be able to reject anticoincidence for objects while retaining some of its appeal by supposing that what infants and others rely on is anticoincidence for substances (Principle 8) instead: No two quantities of a substance (e.g., two different quantities of gold atoms) can be in exactly the same place at the same time. This is compatible with the possibility

¹³ We might try to deal with the conflict between Principle 6, Leibniz's law, and Principle 7, anticoincidence, by treating them as flexible heuristics rather than fixed principles: Perhaps these generalizations work well most of the time but fail in special cases, such as the lump-ring example. But, first, conflicts of this sort may be the usual case rather than the exception. Every object is made up of some quantity of substance, and in many cases, the substance forms a lump-like entity. For example, the bench we are sitting on is constituted by a quantity of wood that forms a chunk. The chunk existed before the bench; so the bench and the chunk are two different objects by Leibniz's law, but they exist at the same place at the same time, contradicting anticoincidence. Second, even if the conflict cases are exceptions, they require explanation. On the face of it, Leibniz's law and anticoincidence do not seem to be mere empirical generalizations but instead ideas central to our notions of object and identity. How could it be, for example, that identical objects could have different properties? If one of the principles turns out to be only sometimes true, we need an account of why we mistakenly considered it inviolable.

that two different objects can be, such as the ring and the lump of gold (as Sattig, 2010, argued), and it may provide the best way to avoid the dilemma associated with these principles.¹⁴ We return to this issue in discussing infants' knowledge of impenetrability.

Evidence about constitution. By 4 years of age, most children are able to identify common materials that constitute an object when asked what an object (e.g., a table) "is made of" (Dickinson, 1987). Most 4-year-olds are also able to group together items "made of the same kind of stuff" in a forced-choice task involving, for example, a glass cup, a chunk of glass, and an aluminum cup. They fail, however, if the triple includes a powder (e.g., a piece of brass, brass powder, and yellowish sand), and they also fail in free-sorting of items (e.g., spoons, chunks, and powders made from plastic, wood, and metal) according to "things made of the same kind of stuff." Their responses suggest "4-year-olds have a concept of material, but this level of classification is less salient than the object-level classification" (Dickinson, 1987, p. 624; see also Dickinson, 1989).

Younger children—2- and 3-year-olds—can correctly generalize novel substance terms if they are told that an object is made of that substance. For example, told that a ball is "made of sponge," they will choose a sponge doll over a plastic ball as the item that is also made of sponge (Prasada, 1993). This result also held for objects constituted of solid substances, such as glass and metal. Recall that children of this age tend to generalize names for solid objects by shape rather than by material (see Figure 3b). Prasada's result reversed this tendency: If children know that the name refers to what makes up the object, they generalize by material instead. Moreover, if 4- and 5-year olds hear a minilecture about how sugar cubes, salt tablets, and other things are made of up of tiny homogeneous pieces, they then generalize substance-relevant properties (Au, 1994). For example, the instructed children are more likely to agree that if a powder "tastes yucky," then a solution of the powder in water would also taste yucky.

These results suggest that even young children have a grasp of constitution—the *makes up* relation that holds between substances and objects. However, in tasks involving solid substances that form familiar objects and in tasks involving transformations between solids or powders and solutions, children may need additional information or reminders about the nature of constitution to match the substances correctly (see the studies cited earlier in the section Substance Structure).

To our knowledge, no previous psychological research has explored the issues about constitution that have puzzled philosophers. These issues await systematic experimental research at the intersection of reasoning and concepts. As an initial foray, we (Rips & Hespos, 2014) asked college students about the relation between a statue and the lump of silver from which it was made. Participants read that a jeweler acquired the lump on March 20 and shaped it into a statue on March 21. They then received the question, "Is the lump of silver on March 21 identical to the statue on March 21?" where "identical" was explained as meaning "equal to," the same relation that the equal sign stands for in mathematics." Participants split their vote almost evenly on the constitution question (47.4% answered "yes"). Participants who answered "no" tended to explain their answer by saying that the

lump no longer existed when the jeweler created the statue because it had lost its lump-like shape (or gained the statue's shape). It could therefore not be identical to the statue. The justifications of participants who thought the lump was identical to the statue are not as easy to summarize, but they seemed to emphasize that nothing had changed to prevent the lump from being the statue.

One might try writing off the second group of responses on the grounds that they arose from a contrived thought experiment. When people perceive a silver statue, they probably classify it as a statue rather than as a lump of silver; so the question of whether the statue is identical to the lump may never naturally arise. We are not confident, however, that this ends the issue. The puzzle is easy to evoke, at least in college students, simply by asking about the relation between the lump and the statue, which suggests that it exposes a gap in their beliefs about constitution. The tendency to classify the object as a statue rather than a lump may be a pragmatic matter, on a par with the mutual exclusivity constraint (Markman, 1989), rather than an indication that no problem exists. Especially when the constituting and constituted items are of about equal complexity (e.g., a piece of paper and a paper airplane), the issue of how they are related at a given time is difficult to dismiss.

A Hypothesis About Object/Substance Differences: Shaping

All physical entities, of course, consist of material substances. But physical objects have something more that stands above their matter. One way to put this "something more" might be to say that physical objects are shaped from their matter, either by natural or agentive forces (see Prasada, 1999). This shaping process imparts significant relational structure on the raw materials, and the presence of this structure means that arbitrary parts or combinations of objects will not be an object. Parts or combinations typically will not share the same structure, accounting for the stratified nature of objects that appears on the right side of Figure 2. From the perspective of this *shaping hypothesis*, what is important about objects is not necessarily their shape because all entities have some shape or other. Instead, what is important is the evidence that shape (and other characteristics, such as function) provide about the objects' shaping. Hence, people take evidence of shaping, such as solidity, regularity, and apparent function, to suggest that they are dealing with objects and not simply substance. A complete theory of shaping would spell out how people weigh and combine these cues, but for our purposes we can rely on the intuition that people somehow take them into account.

We do not mean to suggest that shaping is necessary or sufficient for objecthood because for reasons already mentioned, we doubt that such conditions exist. However, we suspect that people conceive of physical objects as things sustained, internally or externally, by sets of converging forces, so that the more self-sustaining and robust these forces, the more object-like the entity will be. We use *shaping* as an abbreviation for the work of sustaining forces of this type. Our use of shaping is intended to

¹⁴ In the case of mixtures (e.g., tea), the component substances (water and tea extract) intermingle, but we probably still believe that these components are not in exactly the same place. For example, molecules of water and tea extract do not occupy exactly the same locations.

include, not just the initial process that brings an object into existence, but also the processes that support it during its lifetime. This extended sense helps explain what might otherwise seem to be puzzling exceptions. For example, suppose you learn that the regular and solid obelisk that has just appeared in the quad is actually the result of quantum mechanical indeterminism and is simply a random assemblage of particles. We suspect that people would still tend to grant this entity the status of an object, even though nothing systematic has brought it into existence. But as a potential counterexample, this has the problem of taking the shaping idea too narrowly. Once the obelisk appears, ordinary physical forces maintain it, just as they do monuments of the usual variety, supporting it as an object. Although the initial formative process may enter into people's conception of objects, shaping, in the present sense, is an ongoing process.

The shaping hypothesis is one way to flesh out the idea that objects have a type of unity and organization that substances lack. The hypothesis is analogous to the notion of homeostatic clusters of properties that philosophers (e.g., Boyd, 1999) have used to account for the existence of biological species and that psychologists (e.g., Keil, 1989) have used to account for our concepts of these species (among other basic-level kinds). Just as species, such as dogs or robins, depend for their existence on mutually supporting sets of physical forces that maintain them and distinguish them from others, singular objects may depend on similar, but more specialized, cooperating forces to individuate them. For example, individual stars are created and maintained by gravitational forces that contract portions of clouds of hydrogen and other gases. Although many details remain to be filled in about the nature of the sustaining forces responsible for shaping, the shaping hypothesis is a step toward a substantive account of an object's unity and organization, and it seems consistent with the evidence we have encountered so far.

The present hypothesis also is indebted to previous attempts in psychology, philosophy, and linguistics to draw a distinction between objects and substances in terms of form and matter (see the references cited in the introduction to this article). Some of the earlier formulations, however, tie the distinction to the natural or artifact kinds that the objects belong to (e.g., Johnston, 2006; Koslicki, 2008; Prasada & Dillingham, 2009; Prasada et al., 2002). According to such theories, the parts list and unity-and-organization relation for a given object are specified at the level of the object's kind (or basic-level category; see Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). And because this specification spells out what it is for such an object to exist, the parts list and unity-and-organization relation provide an essence for the object. For example, the concept "chair" may provide a list of parts (seat, back, legs, arms) and a unity-and-organization relation that must hold among the parts (the legs must support the seat, and so on). A particular chair ceases to exist if the unity-and-organization relation no longer holds among its parts (e.g., when it is splintered). So the parts and unity-and-organization relation are the essence of the chair.¹⁵

We already registered doubts about tying the unity-and-organization principle to kinds in this way (in the section Constraints on Objects). An object's existence does not seem restricted by the kind to which it belongs: Children as young as kindergartners acknowledge that objects can begin life in one kind (e.g., as

coffee pots) and become members of another (e.g., bird feeders) as the result of simple tinkering (Keil, 1989). Likewise, although unity-and-organization principles are inherently general (as principles), the generality is not necessarily tied to kinds. For example, no general causal principles are true of chairs as a kind; yet causal forces are responsible for holding together particular chairs over the course of their existence. Kind-based theories have a better chance for success with abstract entities, such as numbers or sets, than with the everyday physical objects with which we are concerned here. Of course, we would expect that the shaping relation (or whatever unity-and-organization relation is responsible for objects) would often be similar for members of the same kind, but we suspect that this similarity is imposed from bottom up rather than from top down.

Summary

All ordinary physical objects are made of stuff, but people recognize some looseness in this relationship. For example, they go along with the possibility that an object will continue to exist after its matter has been destroyed and replaced by new matter. One way to explain this independence is that people conceive of an object as held together by a specific structure over its parts, one that allows replacement of some parts with others. For the same reason, recognition of something as an object depends on seeing that it has a nonaccidental structure—that it has been shaped by internal or external forces. According to this shaping hypothesis, factors such as solidity and shape-based function provide hints that this structure is present. Even young children realize that a name for an entity that possesses these cues is probably the name of an object of some type.

By contrast, substances are less choosy than objects because they have no significant structure. Any sum of quantities of a substance is a quantity of that substance. Lack of structure implies that entities that seem not to have been shaped are probably substances, and a name for such an entity is probably the name of a substance of some sort. Young children also understand that substances make up objects. They can identify objects made of the same substance and generalize properties of the substance, at least under favorable conditions in which the *made of* relation is clear. However, this constitution relation puts some conceptual strain on the entire two-part picture of physical nature as divided into separate substance and object domains. Are a chair and the chunk

¹⁵ Prasada and Dillingham (2009) describe a unity principle associated with kinds that relates different aspects of those kinds. For instance, such a principle for frogs would encompass properties such as being green, having the capacity to hop, and being slimy, in addition to physical parts, such as legs (to use Prasada & Dillingham's, 2009, example). According to this theory, individual objects (e.g., a particular frog) have these properties in a nonarbitrary way by virtue of being members of their kind (though the properties are true of the objects by default rather than as a matter of necessity). By contrast, the principle of unity-and-organization with which we are concerned here is a relation that accounts for a group of physical parts composing a single object (e.g., a relation that accounts for why the legs, head, and body of a frog compose a single object rather than being a mere group of these parts). We take these two types of "principles of unity" to be quite different in their aims: Prasada and Dillingham's principle applies equally to objects and substances (e.g., it could explain the transparency of a liquid by virtue of its being water), whereas the principle of unity-and-organization described here applies only to objects (and attempts to explain their objectness).

of wood it is made of one object or two? We currently have little information about how laypeople resolve these uncertainties.¹⁶

Origins of Object and Substance Concepts

The ideas about substances and objects that emerge in the first section of this article inevitably suggest that substances are more rudimentary than objects. Substances are everywhere in the physical world and are relatively unconstrained in their ability to combine and divide. Objects, by contrast, depend on special conditions or relations of unity-and-organization. This notion of the primitiveness of substances is often linked to the idea that concepts of objects depend on special linguistic facts. Perhaps infants are born into a world of substances and only later discover objects when they learn the way their native language refers to them through the apparatus of quantifiers, number marking of nouns, classifiers, and the like (Quine, 1973). They carve the world into objects when they have to contend with expressions such as *a cup* (vs. *milk*), *many cups* (vs. *more milk*), *three cups* (vs. *three pints of milk*).

The developmental evidence that we reviewed earlier, however, suggests that infants can discriminate objects long before they have mastered natural-language devices, such as quantifiers and plurals (e.g., Imai & Gentner, 1997; Li et al., 2009; Soja et al., 1991). This research makes it implausible to suppose that this linguistic apparatus is responsible for people's ability to discern objects. Instead, the standard view in developmental psychology is exactly the opposite: Objects are cognitively simpler than substances, in the sense of being easier for infants to track (Chiang & Wynn, 2000; Huntley-Fenner et al., 2002; Rosenberg & Carey, 2009). But this view is in tension with the principles we discussed earlier. Substances seem less complex internally and less demanding conceptually than objects because they conform to cumulativity and a limited form of divisiveness—they freely combine and divide. Objects, however, require a principle of unity-and-organization, perhaps a type of shaping that enforces stratification. So we need some way to reconcile evidence for the standard developmental view with what seems to be substances' looser structure. This is the task of the present section. Although a number of resolutions are possible, we suggest that infants have knowledge of both objects and substances. The appearance of difficulty with substances may be due to problems of coordinating these two domains (i.e., the two halves of Figure 2).

Infants' Knowledge of Objects

Research on infants has focused on their knowledge of solid, cohesive objects, such as dolls and crackers, and, to a lesser extent, on their knowledge of nonsolid substances, such as sand or water. From our point of view, this focus makes it difficult to separate effects of object status from effects of solidity (and effects of substance status from effects of nonsolidity). The reason for the experimental restriction is that solidity and nonsolidity are stimulus properties that experimenters can easily exhibit to infants. The object/substance distinction, however, is not a perceptual one and is therefore more difficult to convey to prelinguistic children.

The research on object knowledge in infants is vast and has been the subject of earlier reviews (e.g., Baillargeon, 2008). For this reason, we present these results briefly, concentrating on aspects

that bear on the principles mentioned earlier, particularly antioincidence. Research on substance is more recent and less well-known; so we spend more time considering this second body of work.

Impenetrability. According to Spelke (1990), infants isolate entities in their visual environment topologically by grouping perceived points that are connected by continuous paths, paths that include no spatial gaps and are not disrupted by motion. As we mentioned earlier, Spelke's boundedness principle states that if such a continuous path exists, the connected points are part of the same entity. Because a point will always be connected to itself, "if humans represent at most one surface point at each three-dimensional location in the layout, the boundedness principle implies that two objects cannot occupy the same place at the same time. Thus, two distinct objects cannot interpenetrate" (Spelke, 1990, p. 49). Boundedness therefore implies antioincidence for objects. In addition, surfaces that undergo different rigid motions are parts of different objects, unless there is evidence to the contrary (Spelke's rigidity principle, 1990). The types of entities that these principles (together with a few others) pick out are a narrower set than those adults regard as physical objects and that populate the right-hand side of Figure 2. As we noted, some physical objects are nonrigid (e.g., soufflés) and others are disconnected (e.g., tuxedos). This narrower class, however, may be a starting point for children's knowledge of objects.

Evidence that infants follow antioincidence for objects comes from studies showing that they are surprised if an object seems to pass through a solid surface. For example, Spelke et al. (1992) habituated 4-month-olds to an event in which an experimenter dropped a rubber ball from a position above a screen. The infant watched as the ball fell behind the screen, and the experimenter then raised the screen to reveal the ball on the floor of the stage. In test trials, infants saw the experimenter interpose a solid table-like surface that would block the ball's downward path. The screen then covered the table and the bottom of the stage, and the experimenter again dropped the ball behind the screen. When the screen was removed, infants looked longer if the ball ended up on the floor of the stage (under the table, where it had landed before) than if it ended up on the table. The infants seemed to have inferred that the ball was unlikely to have passed through the table during its descent, apparently in accord with antioincidence. Along the same lines, Baillargeon (1995) gave 5-month-olds a preview of a container that, in one condition, was open at the top but had a solid

¹⁶ One might hope that the shaping hypothesis would resolve the difficulties about constitution. In the case of a chair made from a single chunk of wood, we might conceive of the chair as a shaped entity and the chunk as unshaped. If so, we have a single object (the chair) composed of a nonobject (the chunk), and no mystery would arise about how they can be in the same place at the same time. But although this resolution is tempting, it is a version of the "quasi-nihilist" idea that we described earlier (see the section Problems of Constitution) and subject to the same difficulties. Consider a paper airplane composed of a piece of paper (Sattig, 2010) or a statue of a bull composed of an artistically bent cable (Johnston, 2005). Both the piece of paper and the cable seem to be entities shaped by their manufacturing processes and, for this reason, to have object status in their own right. During the time that the paper airplane and the statue exist, we would then have two objects in the same place at the same time. Because of examples like these, we provisionally favor a solution to this problem along the lines that we described (see Problems of Constitution, and for further discussion, see Impenetrability).

bottom or, in a second condition, open at both the top and the bottom. The experimenter then held the container up and poured salt into it, but the infant could see no salt emerging from below the container. Infants looked longer if they had previously seen the bottomless container than if they had seen the one with a bottom. Thus, infants seem to know that neither solid objects, such as balls, nor nonsolid entities, such as a portion of salt, can pass through a solid surface.

Although infants could derive their knowledge of impenetrability from their knowledge of objects, Baillargeon's (1995) findings suggest that they could alternatively derive impenetrability from their knowledge of substances. Suppose that infants believe, in accord with Spelke's (1990) hypothesis, quoted earlier, that at most one surface point can occupy any spatial point in a layout. Then as long as they also think that a surface point can be part of only one substance quantity, they can deduce that substance quantities cannot interpenetrate: Two substance quantities cannot be in exactly the same place at the same time. This gives them anticoincidence for substances. Of course, two substances can intermix, but they cannot occupy exactly the same spatial positions (see footnote 14). We earlier saw an advantage to the idea that belief in anticoincidence comes from substances rather than from objects because the former avoids contradiction with Leibniz's Law (Principle 6; see Problems of Constitution). If the infant data also accord with anticoincidence for substances, we may be able to give a more coherent explanation of how people think about objects and substances by assuming that they possess this principle (along with Leibniz's Law), but do not possess anticoincidence for objects.

Splitting. We suggested that objects are distinguished from substances by objects' dependence on self-sustaining forces (or shaping) that provide their unity-and-organization. We should therefore expect that disruptions to these forces in breaking or splitting would interfere with infants' ability to keep track of objects. Some evidence for this hypothesis comes from experiments in which infants have to track previously fractured items.

In a well-known experiment by Wynn (1992), 5-month-old infants saw a Mickey Mouse doll placed on a puppet stage. A screen then covered the doll, and the infants saw a hand putting (what adults would describe as) a second Mickey behind the screen. When the experimenter removed the screen, infants gazed longer if only one doll remained than if two dolls remained. This result suggests that the infants anticipated that one doll added to another would produce two and were surprised to see only one. Subsequent research with this *addition-subtraction task* has questioned whether infants represent the discrete number of objects or, instead, some continuous quantity, such as the total perimeter of the dolls or the total volume they occupy (e.g., Clearfield & Mix, 1999; Simon, Hespos, & Rochat, 1995). However, when the individual objects are distinctive (Feigenson, 2005), support reappears for discrete number, controlling for continuous quantity (see, e.g., Rips, Bloomfield, & Asmuth, 2008, for a review of these findings).

Infants' performance on the addition-subtraction task drops, however, if they see an experimenter disassemble one of the objects before putting it behind the screen. Figure 4a illustrates an addition-subtraction procedure in which infants watched as a pyramid of Legos was hidden behind one screen and a second pyramid was hidden behind another (Chiang & Wynn, 2000). When the experimenter removed the screens, 8-month-olds were surprised if only a single pyramid remained, replicating the original Wynn

(1992) finding. However, if the infants saw the experimenter disassembling the pyramids into their individual blocks, and then scooping them back into a pile before hiding them behind the screen (Figure 4b), infants did not discriminate between the two test outcomes (one vs. two pyramids). (Their performance improved, though, if they saw the separated blocks prior to seeing the pyramids.) Likewise, Cheries, Mitroff, Wynn, and Scholl (2008) found that when infants saw two crackers hidden in an opaque container and one cracker hidden in a second container (Figure 4c), they would crawl to the container with the larger payoff. But infants failed in a similar procedure (Figure 4d) when they saw the experimenter producing the two-cracker option by splitting a double-sized cracker in half before hiding the halves. Infants' ability to keep track of the objects in a scene is therefore not robust over simple disassembly and splitting, in line with the shaping thesis.¹⁷

Infants' Knowledge of Substances

We saw earlier (Formal Properties of Objects) that object principles, such as stratification, made it possible to count entities, whereas substance principles, such as cumulateness, tend to inhibit counting. For that reason, we should expect to find that infants have difficulty in tasks that require keeping track of substance-like entities. The results from several studies support this expectation. Although infants seem well acquainted with the physical properties of common substances, such as water and sand, they nevertheless have trouble discriminating one from two qualitatively similar quantities of substance.

Amounts. As you might predict from the splitting studies just reviewed, infants perform poorly in addition-subtraction tasks when the items are piles of a nonsolid substance, such as sand (Huntley-Fenner et al., 2002; Rosenberg & Carey, 2009). In one of Huntley-Fenner et al.'s (2002) studies, infants (8 months) observed a pile of sand poured onto the floor of a stage. A screen then covered the pile, and the infants next saw more sand poured behind the screen but in a new location. When the screen was removed, infants did not discriminate in their looking times between the one-pile and two-pile outcomes. Confusion about the spatial overlap between the piles could interfere with the infants' ability to track the number of piles. But the same (null) result occurred if the experimenter covered the first pile with one screen and then poured the second pile behind a second, spatially separated screen. Moreover, infants performed correctly if they saw solid objects with the shape and texture of sand piles (sand objects) lowered, rather than poured, onto the stage. This suggests that infants track objects differently from substances: The experiments' methodologies were identical, only the entities varied.

¹⁷ However, splitting a solid object in two does not impair apes' performance in the reaching task in the way it does for infants in Cheries et al.'s (2008) procedure. Cacchione and Call (2010) found equivalent and above chance choice of the larger amount for both split and unsplit crackers (see Figures 4c and 4d). They also compared the effects of other forms of fragmentation: smashing the cracker into crumbs, splitting it into six pieces, or removing small parts from it. Apes correctly chose the larger amount in all conditions except smashing, and this latter deficit occurred only when the ratio of the size of the smashed cracker to that of the unsmashed cracker was 2:1 (they succeed with a 4:1 ratio). Likewise, rhesus monkeys distinguish artifacts from food objects with respect to splitting, looking longer when artifacts split but not when food objects split; infants, however, do not distinguish the two object types (Shutts et al., 2009).

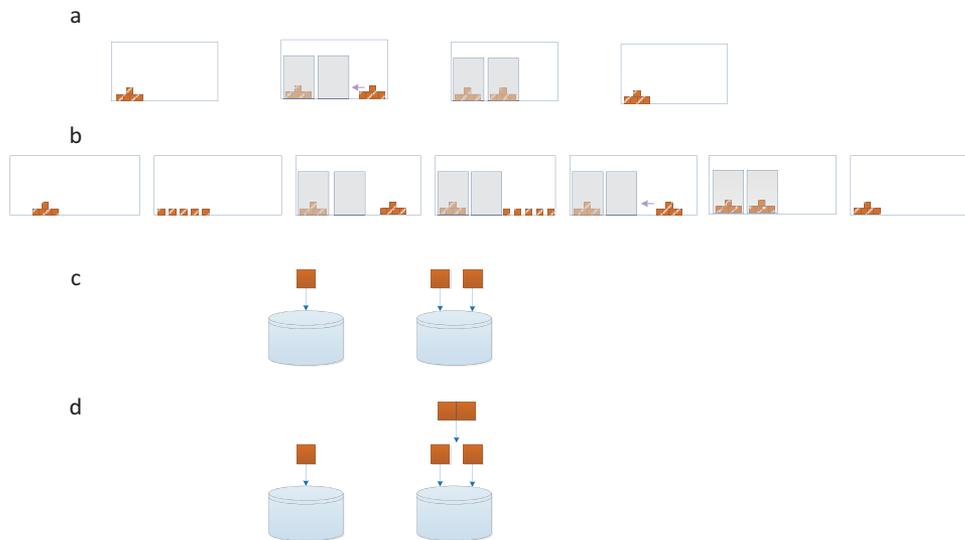


Figure 4. Experimental procedures in infant experiments on splitting. The whole object (Panel a) and split object (Panel b) conditions from Chiang and Wynn (2000, Experiment 1), and the whole object (Panel c) and split object (Panel d) conditions from Cheries, Mitroff, Wynn, and Scholl (2008). See the online article for the color version of this figure.

One possible explanation of these findings is that infants have special perceptual mechanisms for tracking solid objects, such as dolls. Piles of sand may fail to trigger these mechanisms. So infants simply never noticed (or noticed but quickly forgot) the sand piles behind the screen and therefore showed no surprise when the wrong number of piles appeared. However, in other experimental settings, infants do show knowledge of nonsolid quantities. Gao, Levine, and Huttenlocher (2000) presented 9-month-old infants with a transparent container one fourth full of liquid. The experimenter hid the container behind a screen, and the infant then saw the experimenter pour more liquid into the container from above the screen. After the screen was removed, infants looked longer if the container was still one fourth full than if it were three fourths full. The infants therefore seemed to retain some information about the original amount of liquid that they could compare to the new amount. Somewhat older infants (10- to 12-month-old) are able to reach for the larger of two piles of Cheerios after the piles are hidden, provided that they initially see the piles together and provided that the ratio of the piles is at least four-to-one (vanMarle & Wynn, 2011).¹⁸

Infants are also able to discriminate smaller from larger amounts of nonsolid substances when these amounts appear sequentially. Hespos, Dora, Rips, and Christie (2012) used a habituation procedure in which infants (3-, 7-, and 10-month of age) repeatedly witnessed a pile of sand poured onto a plate (the pile was removed after each pouring event). The infants were habituated either to the pouring of a small amount of sand or to the pouring of an amount four times larger. During test trials, the infants saw either a novel amount of sand poured on the plate (the larger size if the infant had habituated to the smaller size or the smaller size if the infant had habituated to the larger) or the familiar amount (larger size if the infant habituated to the larger size or smaller size if the infant habituated to the smaller size). Infants as young as 3 months

looked significantly longer at the novel amount during test than at the familiar amount.

Physics. The results from Gao et al. (2000); Hespos et al. (2012), and vanMarle and Wynn (2011) make the case that infants can encode nonsolid quantities. Infants also can remember them well enough to compare them with new ones, and the precision they show matches that for other quantitative dimensions (Chang, Mikkila, Dora, Rips, & Hespos, 2015). Further studies show that infants will perform distinctive actions when they confront nonsolids and solids (Bourgeois, Khawar, Neal, & Lockman, 2005; Rosenberg & Carey, 2009). For example, they tend to rub their hands more often on liquid surfaces than on solid surfaces (Bourgeois et al., 2005). This finding will come as no surprise to parents who have seen the evident glee of infants smearing creamed spinach around their plate (see Perry, Samuelson, & Burdinie, 2014).

In addition, infants have realistic expectations of how nonsolid substances behave and how this behavior differs from that of solid objects. Hespos et al. (2009) habituated one group of 5-month-old infants to a blue liquid in a tilting transparent cup. The infants could observe that the liquid's surface remained horizontal while the cup was tilted back and forth. A second group of infants were habituated to a blue solid—a piece of plastic that looked identical to the liquid when stationary. In this second condition, infants observed that the top surface of the solid remained parallel to the bottom of the cup while the cup tilted. Hespos et al. tested both groups on each of two scenes: one in which the experimenter

¹⁸ Capuchin monkeys also can discriminate the number of scoops of nonsolid food when an experimenter pours the food into opaque containers (vanMarle, Aw, McCrink, & Santos, 2006). In this study, the monkeys successfully reached for the container with the larger amount of food, and they did so as accurately with nonsolid as with solid food items.

turned the cup over to show the liquid pouring out, and another in which the experimenter showed the solid tumbling out. Infants who had been habituated to the liquid looked longer at the tumbling than at the pouring, whereas infants who had been habituated to the solid looked longer at the pouring than at the tumbling. Similar results occurred if the test scenes showed an experimenter either lowering a cylinder through the contents to the bottom of the cup or lowering the cylinder to rest at the top surface of the contents. Infants who had been habituated to the solid looked longer if the cylinder proceeded to the bottom, but infants who had been habituated to the liquid looked longer if the cylinder stayed on top.

Summary and Implications

Infants discriminate nonsolid substances from solid objects, and they discriminate quantities of nonsolid substance. So why did infants in Huntley-Fenner et al.'s (2002) and Rosenberg and Carey's (2009) experiments fail to notice the change from one pile of sand to two? Figure 5 (adapted from Hespos et al., 2012, Figure 7, p. 565) summarizes infants' successes and failures on tasks that call for knowledge of the number or size of nonsolid quantities. Infants tend to be unsuccessful in addition-subtraction procedures (Figure 5a) in which they have to differentiate two sand piles from one, and in which the piles are of the same size and share the same qualitative properties (Huntley-Fenner et al., 2002; Rosenberg & Carey, 2009). They tend to be successful in procedures in which they have to decide between two differently sized piles presented simultaneously (Figure 5b; vanMarle & Wynn, 2011) or sequentially (Figure 5c; Gao et al., 2000; Hespos et al., 2012). This comparison helps us locate the source of the infants' difficulties. In particular, it allows us to reject the possibilities that infants cannot encode or remember nonsolid piles or cannot register a difference in their size.

We noted in an earlier section (Constitution of Objects by Substance) that pieces such as piles of sand or lumps of gold have an ambiguous status with respect to these domains (see Table 1). Although an individual pile of sand is spatially connected, it does not necessarily have the quality of having-been-shaped that seems crucial to objects. Seeing sand poured onto the floor may not be enough to convince an infant that the resulting piles have nonarbitrary structure. Infants could potentially treat the piles as constituting a summed quantity, on the pattern of $m_1 \vee m_2$ in Figure 2, and they could then proceed to consider the size of this quantity. But with no motive to attend to this summed amount, they may sometimes fail to do so. Any two quantities of substance yield a new quantity, according to the cumulateness Principle 1. But this produces an exponentially increasing number of summed quantities, most of which are of no practical interest. By contrast, tasks for which infants are successful with substances do not require them to individuate substance quantities (e.g., treat $\{m_1, m_2\}$ as distinct from $\{m_1\}$) or to sum them (e.g., determine the total volume of $m_1 \vee m_2$), but merely to compare one to the other (e.g., compare the volume of m_1 to m_2). We doubt, however, that this inability to individuate or to sum substance quantities is absolute. Some circumstances may encourage infants to show more adult-like performance. The suggestion is simply that substances' lack of shaping tends to suppress the ability to distinguish one substance quantity from another, whereas objects' shaping tends to support it

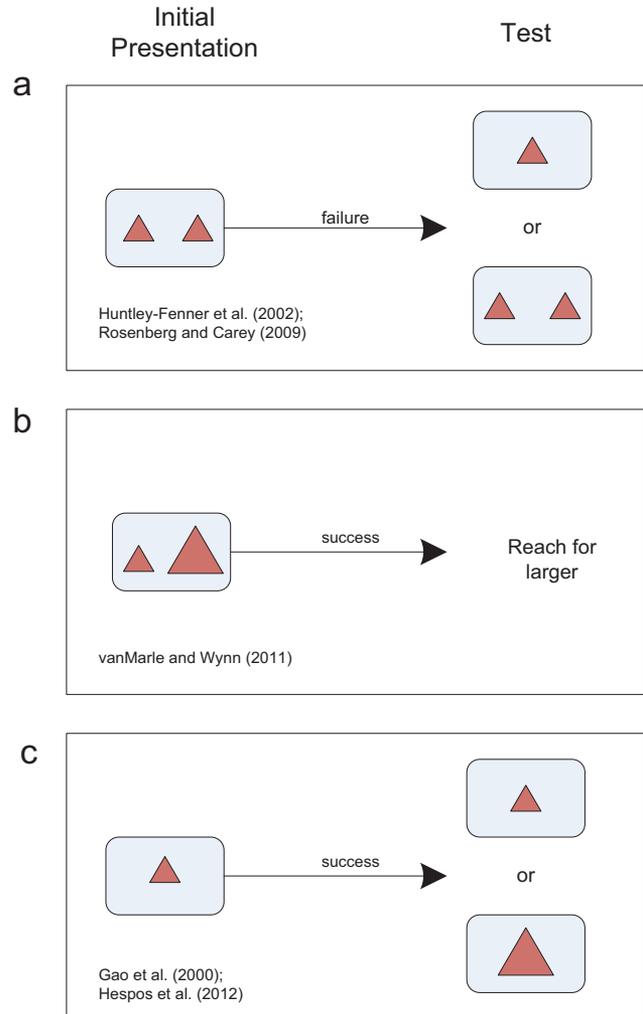


Figure 5. Summary of experimental procedures from studies of infants' ability to discriminate the number or size of piles of nonsolid substances. The *success* and *failure* labels indicate whether infants perform correctly on test trials. From "Infants Make Quantity Discriminations for Substances," by S. J. Hespos, B. Dora, L. J. Rips, and S. Christie, 2012, *Child Development*, 83, p. 565. Copyright 2012 by Wiley. Adapted with permission. See the online article for the color version of this figure.

for reasons that we discussed earlier (see the section Formal Properties of Objects).

Because of stratification, objects typically do not produce other objects by summing; so they do not give rise to the same exponential explosion. Moreover, older children and adults may be more generous than infants are in granting piles of sand the status of objects. For example, they may reason on pragmatic grounds that an experimenter would not have poured a pile of sand on the stage without meaning to create it. Because the experimenter shaped it, the pile may be an object, a kind of artifact, such as a sand castle (Bloom, 1996; Rips, 1989). This hypothesis is, of course, a conjecture, but it is one way to reconcile infants' failure on addition-subtraction tasks (Figure 5a) with their success on other tasks also involving nonsolids (Figures 5b–5c): Only the former puts a premium on counting or summing.

These results do not provide much support for the standard view that objects are innately easier to understand than substances. Although piles of substance may create difficulties in some tasks, the substances themselves do not necessarily pose greater conceptual trouble than objects do. In situations that require physical knowledge of substances' behavior (e.g., Bourgeois et al., 2005; Hespos et al., 2009), infants seem at home in the realm of stuff. Of course, there is a sense in which objects are a special case: Although all objects are constituted of quantities of substance, not all quantities of substance constitute objects, as Figure 2 makes clear. According to the shaping hypothesis suggested earlier, objects are shaped, nonaccidental entities, and a natural corollary of this view is that substances provide the underlying raw materials for whatever natural or artisanal processes succeed in producing the objects.

The shaping hypothesis also leads to a new prediction for nonsolids. If shaping is distinctive to objects, then providing evidence of shaping to infants should enhance their ability to perform correctly in an addition-subtraction task. For example, if instead of pouring sand piles onto the stage, the experimenter molds the sand into piles in such a way that piles will continue to maintain their integrity, then we should expect to see performance closer to that for the solid sand objects in Huntley-Fenner et al. (2002) and Rosenberg and Carey (2009).

At the beginning of this section, we raised the question of whether Quine (1973) was right and children's concepts of objects depend on their knowledge of linguistic quantifiers. Given that infants in the first months of life have different expectations for how objects and substances behave, it is clear that this knowledge is in place prior to the language that frames the differences. The developmental findings are currently insufficient to determine whether knowledge of one domain is conceptually primitive relative to the other. What the developmental data suggest is the possibility that language learning develops by linking linguistic forms to universal, preexisting representations of both objects and substances.

Summary and Conclusions

A particular physical object—say, a cell phone—consists wholly and solely of a quantity of substance at a given time. But according to intuition, the phone can continue to exist through changes in its matter. The phone still exists, for example, after a new battery replaces an old one. These facts imply that an object cannot be reduced to a particular quantity of matter. One way to think about the difference between them is to suppose that people represent a physical object, but not its matter, as a relation applied to a set of parts—a unity-and-organization principle for the object. Parts such as the battery, the processor, and the screen of the phone have to stand in a particular relation to each other for the whole to qualify as a physical object. For example, the battery powers the processor; the processor transmits information to the screen; and so on. A mere heap of cell phone parts does not qualify as a physical object. Our hunch is that the unity-and-organization principle for physical objects is the result of the causal forces that produce and sustain these objects. Design and manufacturing processes put the cell phone together in such a way that its parts are joined by mechanical and electrical linkages that maintain the system. By contrast, substances have no unity-and-organization principle.

One consequence of the unity-and-organization relation is that we cannot get a new object by arbitrarily dividing or aggregating old ones: Dividing and aggregating do not preserve unity, in accord with the stratification Principle 5. The top and bottom thirds of a cell phone is not an object. Neither is the sum of two or more phones. But because substances do not have unity-and-organization relations, they divide and combine more freely, following the cumulateness Principle 1 and a limited form of the divisiveness Principle 2. Any sum of a quantity of matter is another quantity, and so is any part of such a quantity, setting aside molecular limits. From this point of view, then, objects are a special case. A quantity of substance completely fills every spatial region, but only certain quantities of substances constitute objects.

How do we recognize whether a spatial region contains an object and not just a sum of matter? We usually do not have direct access to the causal forces responsible for an object's unity. Experiments suggest that people rely instead on a number of cues as indirect evidence. Solidity, repetition of instances with the same shape, discreteness, regularity of shape, and functional relevance all hint that the entity is put together and maintained in a nonarbitrary way—"shaped" by either physical or social forces. These factors testify to the nonaccidental nature of the entity, the presence of a unity-and-organization relation that stands behind it. These cues also signal that a singular referring expression for an entity denotes an instance of an object category. If you hear someone say *Look at this glux* while pointing to a discrete solid, you are likely to suppose that *gluxes* are a category of objects that include other instances with the same relation governing its parts. If someone points in the direction of a nonsolid or an aggregate, though, you are more likely to suppose that *glux* is a type of substance that includes stuff with the same material composition.

Preschool children already appreciate that substances "make up" objects. They can group objects of different types according to what they are made of, as long as the quantities of a substance are not too dissimilar perceptually. More complex ideas about substances—for example, that the same substance can exist as both a solid and a powder—require further learning. Adults also are able to understand transformations that take an object into its constituent substance (e.g., in interpreting sentences such as "After the explosion, there was cell phone all over the floor") or that take a quantity of substance into an object (e.g., in interpreting "He put two waters on the table"). But even adults appear to have uncertain intuitions about cases in which a substance-like entity makes up an object. They believe a lump of silver can make up a ring and a piece of paper can make up a paper airplane, but are unclear whether the lump is then identical to the ring or the piece of paper to the airplane.

Recent research shows that infants distinguish properties of certain substances—liquids and aggregates—from properties of solid objects. Infants, for example, understand that liquids pour out of a container rather than tumbling out. They also appreciate certain quantitative properties of these substances—that one amount of sand is bigger than another. Infants are neither object blind nor substance blind. Where infants run into trouble is in tracking the number of similar piles of substances like sand. Although they can successfully predict whether the experimenter has placed one or two solid objects behind a screen, they seem unable to do so for nonsolid piles. One hypothesis about the difficulty of this task is that it demands viewing substances as

objects. What changes over development may be the flexibility to shift between object and substance concepts.

Although language could not be responsible for infants' initial knowledge of particular substances and objects, it could affect the way older children and adults conceptualize these domains. The count/mass distinction is a natural place to look for linguistic influences on object and substance concepts, as theorists at least since Whorf (1956) have argued. Speakers of languages with no count/mass distinction are more willing to generalize category terms for ambiguous entities to substances rather than to objects (e.g., Imai & Gentner, 1997; Imai & Mazuka, 2007; Li et al., 2009). However, they do not differ from speakers of count/mass languages in direct classification of such items as objects versus substances (Barner, Inagaki, & Li, 2009; Li et al., 2009; see Gleitman & Papafragou, 2012). We can add this uncertainty to other gaps in our knowledge of people's concepts of objects and substances. For example, we currently have no empirical results on how people view mixtures, such as coffee or juice, which might be said to have vague minimal parts. Along the same lines, we do not know whether people can think of substances as having no minimal parts (as infinitely divisible "gunk"). And we have little information about their knowledge of the way objects and substances interact (e.g., when substances fill, flow through, or are contained by objects), despite the importance of these interactions in scientific contexts (see Davis, 2008; Hayes, 1985, for formal theories).

The two-domain picture of objects and substances that we have pursued here seems consistent with the evidence, but it raises the question of why people maintain this double account. Why do they need to know about both a chair and the wood that composes it? We suspect that doing so helps them answer different questions about the nature of entities. Sometimes they need to understand basic physical properties that govern weight, taste, buoyancy, and other fundamentals that knowledge of substances can supply. But they also may need to know properties at a higher level of organization—how a system of parts operates over time—and for information of this sort they need to keep objects in view.

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Appendix

Stratification and Its Consequences

The stratification principle (i.e., Principle 5) may seem to be inconsistent with divisiveness (Principle 2) in the same way that atomism (Principle 4) is inconsistent with gunkiness (Principle 3). However, this turns out to be incorrect, for the following reason:

Assertion 1: Any atom satisfies both Principles 2 and 5.

Proof: An atom e already decomposes into a set—namely, $\{e\}$ —whose single member has no proper parts, thus satisfying Principle 5. The only (proper or improper) part of e is e itself (i.e., $e \leq e$), which must belong to the same substance type, satisfying Principle 2. So e is compatible with both Principles 2 and 5. \square

What is true, however, is the following extension:

Assertion 2: Nothing can jointly satisfy Principles 2, 3, and 5.

Proof: To show this, we first note that Principle 5 implies the following restriction on objects (see [Simons, 1987](#)):

Principle $$:* If o is an object of type O , then there is an object $o' \leq o$, but no object o'' of type O such that $o'' < o'$.

To see why, recall that Principle 5 says that o can be completely decomposed into a set S of objects, none of which has a proper part

of type O . (A complete decomposition of o is one in which: (i) every member of S is a part of o , (ii) no members of S have any parts in common, and (iii) every part of o not in S has a part in common with some member of S ; see [Zimmerman, 1995](#).) So if Principle 5 holds of an object o of type O , then there is an object o' in the decomposition of o , where o' has no proper parts. That is, $o' \leq o$ but there is no $o'' < o'$, which is what ($*$) asserts.

We can now prove that no entity can satisfy Principles 2, 3, and $*$. Suppose, for contradiction, that e is such an entity of type E . By Principle $*$, there is an entity e' such that $e' \leq e$, and by (2), e' is also of type E . However, Principle 3 stipulates that there is an $e'' < e'$, and e'' is again of type E , according to Principle 2. But this contradicts the second part of Principle $*$. So, as claimed, nothing can obey Principles 2, 3, and $*$.

We saw earlier that Principle 5 entails $*$. If anything satisfied Principles 2, 3, and 5, it would therefore satisfy Principles 2, 3, and $*$. Because we proved that the latter is impossible, so is the former. \square

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