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ARTICLES

Young Children's Changing Conceptualizations of Brain Function: Implications for Teaching Neuroscience in Early Elementary Settings

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Research Findings: Two exploratory studies explored young children's views of brain function and whether these views can be modified through exposure to a brief classroom intervention. In Study 1, children aged 4–13 years reported that the brain is used for "thinking," although older children were more likely than younger children to also endorse a role for the brain in sensory activities such as seeing, smelling, or tasting. This replicates prior findings that young children view brain functioning as being limited to a role in intellectual activities. Study 2 showed that this narrow view of brain function could be broadened through a brief classroom intervention with 1st graders that emphasized connections between the brain and body. Compared with a control condition, the intervention significantly increased awareness of the brain's involvement in sensory experiences, although it had no effect on children's responses to stories involving the magical transformation of a protagonist's brain. *Practice or Policy:* Basic aspects of brain function can be taught at the elementary level without requiring a great deal of specialized knowledge on the part of teachers. Such instruction could form an important part of early foundational learning about human biology, an area that is currently neglected in early educational curricula.

Prior research has suggested that young children have a relatively limited view of brain function, viewing the brain as being unnecessary for many kinds of human activities. In their classic work in this area, Johnson and Wellman (1982) found that children endorsed a role for the brain in thinking, knowing, dreaming, remembering, and "being smart," with around 90% of kindergartners

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and 99% of third to fifth graders stating that the brain is needed for these mental acts. In contrast, only 27% of kindergartners affirmed a role for the brain in seeing, hearing, tasting, and smelling, with this percentage rising to only around 50% in third and fifth graders. This suggests that young children conceptualize the brain as an entity mainly used for thinking and other intellectual activities, somewhat analogous to a container for storing memories and facts (Gottfried, Gelman, & Schultz, 1999), as opposed to seeing the brain as having a active role in everyday activities and life processes.

We suggest four interrelated reasons why young children's views of brain function may be quite limited. First, young children hear very few instances of the word *brain* in everyday conversation (Corriveau, Pasquini, & Harris, 2005). Second, because children cannot observe their own brains, they rely on others' testimony about them (Gelman, 2009). In this respect, the way in which young children are informally told by adults about the function of the sense organs (e.g., ''your eyes are for seeing'') may reinforce children's notions that the brain is not involved in sensory activities. Third, children are not generally taught about brain function until middle school, with earlier mentions of the brain in educational settings being very sparse. Fourth, young children may not be able to grasp the relations between bodily organs such that they see individual organs working in isolation and not as part of interconnected systems (American Association for the Advancement of Science [AAAS], 1993).

The lack of attention to brain function and other basic neuroscience concepts in elementary settings can be seen as a function of a general underemphasis on science at this level. State and national education standards in the United States have long tended to focus on the youngest students gaining proficiency in mathematics and literacy, leaving science education in elementary school on the back burner. Advocates have cited two reasons for the lack of attention to nurturing science education in elementary schools (Cameron & Chudler, 2003; Leshner, Malcom, & Roseman, 2010). First, many elementary school teachers lack formal training or preparation in science. Second, the lack of federally mandated science standards has led to inconsistencies and disparities between states in content and the level of rigor in early science curricula. We might add another impediment, which has been the tendency to view elementary school children as not being ready for the kind of thinking involved in ''doing science'' (for a critical review of this issue see Metz, 1995). However, although there are clearly developmental limitations on young children's thinking, a growing body of work is showing that early elementary school children are capable of engaging with the practice of knowledge building from a scientific perspective (see, e.g., Metz, 2008).

In part because of these factors, areas of science that could be introduced in elementary school classrooms have fallen by the wayside. Our focus here is on neuroscience, which along with other related aspects of human biology has been particularly neglected in elementary school curricula. In some ways this omission seems counterintuitive. From a young age children are curious about how their bodies work, and it would seem that learning about the function of bodily organs, including the brain, would be an appropriate part of early science curricula (Cameron & Chudler, 2003).

Without a relevant set of formal standards for elementary school curricula, education professionals interested in introducing neuroscience concepts at the elementary level may be unsure about where to turn for such information. However, a number of organizations have created supplemental educational material that can be integrated into a typical elementary school science curriculum. Examples include educational resources from ''Brain Awareness Week'' by the

Dana Foundation, ‘‘Brain Link’’ by the Baylor College of Medicine, ‘‘Brain Power’’ by the National Institute on Drug Abuse, and ‘‘Human Brain and the Senses’’ by the Lawrence Hall of Science/Full Option Science System (see Cameron & Chudler, 2003). Other resources include online materials and activities such as the extensive Neuroscience for Kids website that is based at the University of Washington.

As part of wider curricular recommendations, national organizations such as the AAAS, the National Research Council, and the Society for Neuroscience have also developed sets of standards detailing what elementary and middle school students should learn about neuroscience (for a summary see Roseman & Koppal, 2010). We focus here on the AAAS standards for K–12 education from the publications *Benchmarks for Science Literacy* (AAAS, 1993, 2009) and the *Atlas of Science Literacy* (AAAS, 2001, 2007). As part of a wider section titled ‘‘The Human Organism: Basic Functions,’’ standards related to the understanding of the brain are presented in Unit 6.3 of *Benchmarks* (see Table 1). This section also describes how children in the primary grades view bodily organs (including the brain) as existing and functioning independently from

TABLE 1
Content Standards and Goals From Unit 6.3 (“The Human Organism: Basic Functions”) of the American Association for the Advancement of Science *Benchmarks for Science Literacy* (1993, 2009)

Grade level	*Benchmark content*	*Level-specific goal related to brain function*
K–2	Children at this level think each organ has its own independent function. The eyes are for seeing, the brain is for thinking, the stomach is for digesting food, and so forth. Only later will students be able to learn how organs work in coordinated ways to make systems. One can expose young children to some of the facts in response to their questions, but they cannot understand those facts until they are older.	By the end of the second grade, students should know that the brain enables human beings to think and sends messages to other body parts to help them work properly.
3–5	At this level, children can begin to view the body as a system in which parts do things for other parts and for the organism as a whole. Models help children to see and touch the internal organs and to know where they are located in the body. Questions about familiar body systems can be useful in getting students to start thinking about systems generally. Students can then begin to understand that each organ affects and is affected by others.	By the end of the fifth grade, students should know that the brain gets signals from all parts of the body telling it what is going on there. The brain also sends signals to parts of the body to influence what they do.
6–8	Students can now develop more sophisticated understandings of how organs and organ systems work together. The circulation of blood carries digested food to the cells and removes wastes from them. Nerves and hormones carry messages that contract muscles to help the organism respond to its environment. Asking ‘‘What if?’’ questions such as ‘‘What might happen if some other parts weren’t there or weren’t working?’’ can stimulate students to reflect on connections among organs.	By the end of the eighth grade, students should know that interactions among the senses, nerves, and brain make possible the learning that enables human beings to predict, analyze, and respond to changes in their environment.

other organs within the body. As children advance to middle and upper grades, their understanding shifts to a more sophisticated systems view of the body in which organs work together to enable functioning within local systems and across the body as a whole.

In the current paper we present findings from two exploratory studies. In the first study, we wished to replicate prior findings on the development of children's conceptualizations of brain function in a contemporary sample. Specifically, we used an online survey to gather parent reports of children's answers to a variety of questions concerning brain function. As noted previously, Johnson and Wellman (1982) found that young children viewed the brain as being primarily involved in ''mental acts'' such as thinking, remembering, or knowing as well as in overt intellectual acts such as counting, reading, and writing. In contrast, young children reported that the brain is not needed for sensory activities (e.g., seeing or hearing) or involuntary actions (e.g., coughing or blinking). Almost 30 years has elapsed since Johnson and Wellman's study, and over that time there has been a sizeable increase in neuroscience research and its dissemination. It therefore seems reasonable to ask whether their findings are still applicable in a contemporary sample. Indeed, it has been suggested that findings from neuroscience are having an increasingly strong influence on the ways in which people conceptualize behavior and mental experience, with the emergence of what Rodriguez (2006) referred to as a ''folk neuropsychology.'' It is possible that such changes in the ways of thinking and talking about the brain may filter down to influence what young children encounter on this topic.

The second study involved a small-scale classroom intervention with first graders that was designed to teach children about the brain's broader involvement in everyday sensory activities and feeling states. We know of very little work that has attempted to modify the way in which young children conceptualize brain function. Some interesting work with older children and adolescents has shown that changing children's concepts of the brain can improve their academic performance (Blackwell, Trzesniewski, & Dweck, 2007). As part of their original study, Johnson and Wellman (1982) tested a small subset of fifth graders who had been taught about the brain as part of their science curriculum. Despite being taught about both the voluntary and involuntary functions of the brain, these fifth graders performed just as poorly at attributing a role for the brain in involuntary acts as other fifth-grade students who had not yet been taught about the brain. However, this observation was essentially incidental to a descriptive study and was not part of a more controlled attempt to assess the impact of a particular intervention.

In evaluating the effects of our classroom intervention with first graders we had two aims. The first and primary aim concerned whether our intervention would help children understand that the brain is involved in more than thinking, knowing, and remembering. Our rationale was partly that an increased awareness of the brain's continuous involvement in everyday activities may have a number of positive benefits in the elementary years. For example, if such an awareness could be consistently promoted and reinforced, it may promote young children's understanding of the need to ''protect'' their brain (e.g., through maintaining a healthy diet, avoiding drug use, wearing a bicycle helmet). It may also facilitate their understanding of mental and/or physical disabilities of peers or adults who are familiar to them but who are ''different'' because of a neurological problem (Cameron & Chudler, 2003).

The second aim of our intervention study concerned whether learning about the involvement of the brain in everyday sensory activities may also impact young children's thinking in the domain of personal identity. In this respect we were influenced by prior studies that examined children's responses to questions about change or continuity in an individual's psychological characteristics following hypothetical transformations of his or her brain. In one such study, when asked about the result of transplanting a child's brain into a pig's body, most 7-year-olds responded that the resultant creature would have the psychological characteristics of a child even though its body was that of a pig (Johnson, 1990). In contrast, 5- and 6-year-olds were much less likely to endorse this view and tended not to attribute human characteristics to the creature. In another study of children's responses to a series of vignettes about body/brain transformations (Corriveau et al., 2005), 7-year-olds (but not 5-year-olds) saw the continuity of the brain as being important for the preservation of characteristics such as the name, preferences, memory, and skills of the transformed character (see also Gottfried et al., 1999).

In their interesting discussion of these various findings, Dalton and Bergenn (2007) suggested that in the early elementary years children are in the process of adopting the notion that the brain is a container-like entity that is the seat of personal identity because it houses the individual's thoughts, memories, and preferences. However, this suggestion exposes a certain paradox, which is that while young children are developing an understanding that the brain is involved in almost all human activities and that it is linked to the rest of the body (Johnson & Wellman, 1982), they are concurrently adopting the notion that the brain is a kind of container that would retain its contents (e.g., thoughts, memories, and preferences) if transplanted into another individual (Johnson, 1990). However, Dalton and Bergenn suggested that particularly in the early elementary school years, when children are still unsure of these relations, students could be exposed to information that may push their conceptualizations toward a more dynamic view of brain function that puts less emphasis on the (rather inaccurate) notion of the brain as a container.

We follow this suggestion of Dalton and Bergenn (2007) with the following somewhat speculative proposal: If young children could come to a realization that the brain is needed for more than just thinking, they may grasp that brain functioning is intimately connected with other bodily systems (e.g., through the connection of the brain to the sense organs). From this observation, children may begin to realize that personal identity may not depend on the ''contents'' of the brain per se because brain function is intertwined with the particular opportunities and constraints that are afforded by the nature of the body (Marshall, 2009). If indeed such a realization were reached, it could impede children's acquisition of what Johnson (1990) termed the ''Western folk psychological notion'' that the continuity of the brain (but not the body) is necessary for the maintenance of personal identity. We further speculate that if this were the case children may have a more flexible view of how changes in the nature of an individual's brain would affect the continuity of his or her psychological attributes.

STUDY 1

Method

In an online survey, parents were asked to administer 10 questions about the brain to their child and to record his or her responses on the web page of the survey. The survey questions and background information for the study were placed online at a popular survey hosting website (www.surveymonkey.com). The survey was promoted on various family-related websites and was available online for a period of around 4 months. Before they began, parents were asked to provide consent for their child to participate using an online consent form. If the child was older than 7, the child also had to agree to participate using an online assent form. The survey was advertised as being for parents with children from the ages of 4 to 18 years, although given our immediate focus on early education we only report data from children up to age 13.5 years.

Parents were informed that their survey responses were completely confidential and that no personally identifying information (including IP address) would be recorded. Background information was obtained from parents about their child's age as well as which country the parent and child were residing in. Further demographic information (e.g., about parental education) was not collected. For the 10 questions on the survey, parents were given fixed choices (yes/no/not sure) for recording their child's response to each question. A text box was also included for each question for parents to elaborate on their child's response if necessary. Although these opportunities for further responses were given, very few parents entered information in the text boxes, thus precluding an analysis of the qualitative responses.

The questions on the survey were based on those of Johnson and Wellman (1982), who undertook an extensive assessment of children's concepts of brain function. In a series of three studies, Johnson and Wellman asked children to make judgments about whether the brain was needed to perform certain activities and whether similar activities could be performed without a brain. In the current study, our questions took a slightly different format, asking children whether they were ''using their brain'' during certain everyday sensory activities and experiences.

The set of questions began with two questions about the body followed by six questions about the brain's involvement in everyday sensory activities, feeling states, and thinking. Finally, two additional questions concerned the nature of the relation between the brain and mind. This latter issue is not immediately relevant to the current paper, and thus children's responses to the final two questions are not reported here.

The initial two questions in the survey asked about the involvement of particular body parts in everyday activities, as follows:

- ''When you smile, are you using your mouth?''
- ''When you walk, are you using your legs?''

The purpose of these questions was to broadly ensure that children could answer questions of this general type (i.e., when you . . . are you using your . . . ?) using relatively obvious examples. The six target questions then utilized a similar format to describe a certain activity or feeling state and then ask whether this activity or state utilizes the brain, as follows:

- ''When you look at things, are you using your brain?''
- ''When you smell flowers, are you using your brain?''
- ''When you are running, are you using your brain?''
- ''When you taste something delicious, are you using your brain?''
- ''When you are feeling happy, are you using your brain?''
- ''When you are thinking about something, are you using your brain?''

Complete responses were obtained from 86 families with children between 4 and 18 years of age. The majority of responses ($n = 70$) were from families in the United States, with the remainder ($n = 16$) coming from a variety of countries. We limit our analyses here to the 53 children (26 female) from the United States who were younger than 13.5 years ($M = 8.2$ years, $SD = 2.8$, range = 4.2–13.3), which corresponds to the lower three quartiles of the age distribution of the overall sample.

Results

For the initial questions about the involvement of parts of the body in certain activities, the number of children who responded in the affirmative was 49 (93%) for the smiling question and 52 (98%) for the walking question. This suggests that the participating children were generally able to accurately answer questions of this type.

To broadly capture the expected age-related differences on the six questions about the brain's involvement in sensory activities and feeling states we performed a tertile split by age to create three groups of children in the age ranges of 4.2 to 6.5 ($n = 17$), 6.6 to 9.2 ($n = 18$), and 9.3 to 13.3 ($n = 18$) years. For most of the questions there appeared to be a strong age-related effect (see Table 2, with older children being much more likely than younger children to endorse the brain's involvement in the processes of looking, smelling, running, tasting, and feeling happy. In contrast, for the question of whether the brain is being used ''when you are thinking about something,'' the vast majority (51/53, or 96%) of the entire sample responded in the affirmative. There was very little variation with age in children's responses to this question, with the percentage of children with affirmative responses remaining very high across the three age groups.

To further quantify these effects we computed a composite score that reflected the number of affirmative (''yes'') answers to the five questions about whether the brain is being used during the everyday activities and feeling states (not including the ''thinking'' question). Higher scores on this composite reflect increased agreement that the brain is being used during each of the relevant activities or feeling states (looking, smelling, running, tasting, and feeling happy). There was a significant correlation between children's age and the composite score, $r(51) = .52$, $p < .001$, although the patterning of means from the individual items suggested that this relation was unlikely to be linear.

To investigate further we used a univariate analysis of variance (ANOVA) to compare the three age groups on the composite score, with gender added as an exploratory between-subjects factor. There was a significant main effect of age group, $F(2, 47) = 6.98$, $p < .01$; with no significant effect of gender, $F(1, 47) = 0.01$, $p = .99$; and no significant interaction between age and gender, $F(3, 47) = 1.60$, $p = .21$. Figure 1 shows the pattern of means for the composite score

TABLE 2
Percentage of Affirmative Answers by Age Group in Study 1 for the Questions About the Involvement of the Brain in Various Activities

Question	*4–6.5 Years (n = 17)*	*6.5–9 Years (n = 18)*	*9–13.5 Years (n = 18)*
Looking at things	29	44	89
Smelling flowers	12	39	72
Running	47	44	83
Tasting something delicious	12	39	83
Feeling happy	47	39	72
Thinking	94	94	100

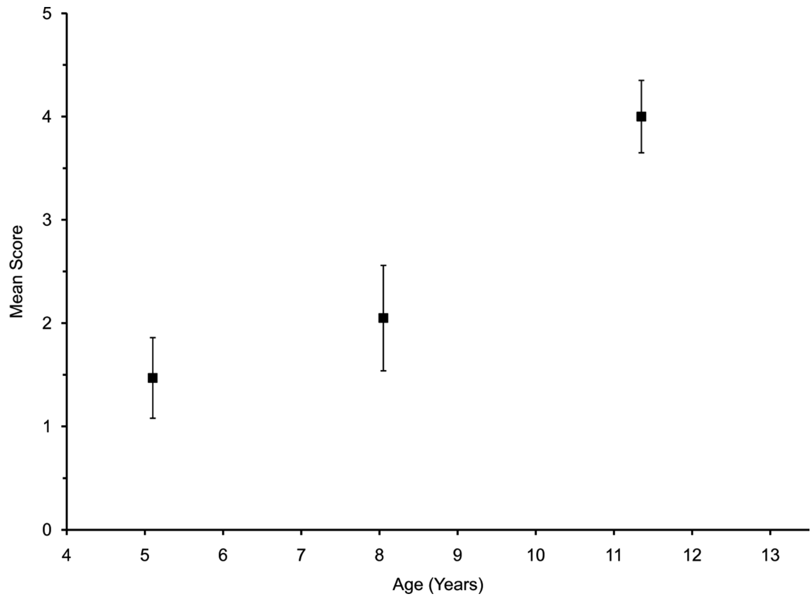

FIGURE 1 Mean score (out of 5) for each age group on the composite measure of the brain's involvement in sensory activities and feeling states in Study 1. Each point corresponds to the mean score for each age-based tertile ($n = 17$ or 18). Error bars indicate ± 1 *SE*.

across the age groups. Post hoc Bonferroni tests revealed that the mean scores for both of the two younger age groups differed from the mean scores for the oldest age group (both comparisons $p < .01$). The means for the two younger groups did not differ significantly from each other ($p = .99$). Further evidence for an age effect came from the informal observation that until 9.2 years of age (the lower cutoff of the upper age group) there were still some children who scored zero on the composite measure, indicating that they endorsed no role for the brain in the specified sensory activities and feeling states. Beyond that age point, no child had a score of zero on the composite score.

STUDY 2

Method

Participants were 129 children (59 boys, 70 girls) in first grade in elementary schools in urban Philadelphia (Pennsylvania). The children ranged in age from 5.9 years to 8.1 years ($M = 6.8$ years, $SD = 0.38$). Parental consent was obtained for children to participate and for audio to be recorded during the data collection sessions. Information on child ethnicity and parental education was also collected from parents. The principal of each school provided consent for his or her facility to be involved in the study. First-grade children were recruited from nine private and charter schools in Philadelphia; eight had religious affiliations (all Christian, primarily Catholic) and one was secular. According to U.S. census data from 2000, the median income for zip codes in which the schools were located was $32,974, and their racial and ethnic composition closely mirrored that of the sample in our study. The racial/ethnic makeup of the sample was 52.5% Caucasian, 25.4% Black or African American, 11.0% other/more than one group, 6.8% Hispanic/Latino, and 4.2% Asian. Around 71% of mothers of the participating children had completed some college or obtained a college degree.

Each school was assigned to either the experimental condition or a control condition. Assignment of a school to either condition was made prior to the initial visit to that facility. Over the course of data collection, we attempted to match participating schools based on their geographic proximity to each other as well as the estimated number of participants from each school. The final (ninth) participating school was assigned to the control condition in order to balance overall group sizes. Within each matched pair, participants from one school received an in-class experimental intervention consisting of a 20-min lesson about brain function in which the relation of the brain to the senses was emphasized (see below and the Appendix). Participants from the other school in each pair (as well as the final school visited) received a control lesson of similar duration about an unrelated topic (honeybees). The intervention and control lessons were delivered by three members of the research team in conjunction with the classroom teacher.

The final sample comprised 67 children in the intervention group (34 female, mean age $= 6.8$ years, $SD = 0.39$) and 62 children in the control group (36 female, mean age $= 6.9$ years, $SD = 0.36$). In terms of group composition, Caucasian children were overrepresented in the control group (66%) compared with the intervention group (40%). Mothers in the control group were also more likely to have completed college or to have some college education than mothers in the intervention group (82% vs. 65%, respectively).

In addition to the classroom lesson, each participating child had a one-on-one session with an experimenter in which he or she was asked a set of questions about brain function. Children's responses to these questions were gathered at two time points: The first (baseline) time point was immediately prior to the experimental or control lesson, and the second time point was 3 weeks later, during a follow-up visit to the school. At both time points the questions that children were asked fell into two main categories. The initial set of questions concerned whether the brain is being used when people are carrying out certain everyday activities, and questions tapped other aspects of general knowledge about the brain. These questions were followed by the presentation of two vignettes (accompanied by pictures) concerning magical transformations of a character's body or brain. A second set of questions probed children's understanding of these stories and their views on the personal identity and psychological characteristics of the transformed character. At each time point the total duration of the question/vignette sessions was around 12 min per child.

Questions about the brain's involvement in everyday activities. Each child was initially asked two questions about the involvement of the body in everyday activities in order to ensure that children across the sample could answer questions of this general type:

- ''When you smile, are you using your mouth?''
- ''When you walk, are you using your legs?''

Following these questions, children were asked five additional questions about the involvement of the brain in a variety of sensory activities and feeling states:

- ''When you look at things, are you using your brain?''
- ''When you smell flowers, are you using your brain?''

- ''When you are running, are you using your brain?''
- ''When you taste something delicious, are you using your brain?''
- ''When you are feeling happy, are you using your brain?''

Questions about other aspects of general brain knowledge. Participants were also asked the following five questions concerning other aspects of their general knowledge of the brain, including its involvement in thinking and remembering:

- ''What part of your body do you use to think?''
- ''Do you need a brain to remember?''
- ''Does a rock have a brain?''
- ''Does a tree have a brain?''
- ''If you could see inside someone's head, would you be able to see their brain?''

Children's responses to the questions about the brain's involvement in everyday activities and about other aspects of brain knowledge were coded by the experimenter and a blind coder (see below) as reflecting three possible answers: yes/no/don't know. The one exception was the question about which part of the body is used to think, which was coded as ''brain'' or ''other.''

Brain–body transformation stories. Following these questions, each participant heard two stories involving the transformation of a young child's brain or body. Questions about these stories were designed to tap into children's understanding of the brain's role in determining personal identity. If a child's brain was magically moved into an animal's body, what would the resultant creature think, prefer, and feel? Conversely, if a child's brain became that of a different animal but his or her body remained the same, who would the child be?

Four template stories were developed based on the vignettes used by Corriveau et al. (2005), with the addition of custom picture books to enhance children's understanding. Each story template had two different versions: (a) A wizard casts a spell causing the character's brain to turn into a particular animal's brain but still allowing the character to maintain his or her original body; (b) A wizard casts a spell causing the character's body to turn into a particular animal's body but still allowing the character to maintain his or her original brain. Corresponding picture books were created to accompany each story. All stories followed the same format, which is shown in the following example of one brain transformation story:

> Once upon a time, there was a girl named Molly. Whenever someone asked her, ''Who are you?'' Molly always said, ''I'm Molly!'' One day, Molly was walking on a beach collecting seashells for a sandcastle that she was building. Molly is really good at building sandcastles. As she was walking on the beach, she was thinking about her favorite food, macaroni and cheese. Then, she ran into a wizard. The Wizard looked at Molly and said, ''I'm going to put a spell on you! I'm going to turn your brain into the brain of a seal.'' The wizard waved his magic wand and Molly's brain turned into the brain of a seal. Her body was still the same, but her brain turned into the brain of a seal.

After having heard the story once (in combination with the picture book), participants were asked a question to confirm that they knew what transformation had taken place as a result of the wizard's spell. For the example story above the child would have been asked ''What did the wizard do to Molly in the story?'' At the first time point, 67% of children correctly verbalized what the wizard did to the character, with this percentage being 87% at Time 2 for this initial question. Regardless of whether the participant gave the correct answer to this initial question, the experimenter again explained the outcome of the transformation using the storybook pictures as guides. After reading the story a second time, the experimenter then asked the child again what had happened to the character as a result of the wizard's spell. If the child did not get the answer correct, the experimenter again explained the outcome of the transformation using the storybook pictures. If participants incorrectly answered the question a third time, their responses to the stories were not analyzed further. Only two participants' data were discarded because they did not provide correct answers within three attempts. Data from five further participants were discarded because of procedural errors during the story reading and questioning session.

As a further test of story comprehension each child was also asked two forced-choice understanding questions to confirm that he or she knew what type of body and what type of brain the character ended up with after the transformation: for example, ''What does Molly look like now, a seal or a little girl?'' and ''Whose brain does Molly have now, her brain or a seal's brain?'' At both time points, the vast majority of children (>94%) answered these questions correctly on the first attempt.

Based on Corriveau et al. (2005), children were then asked five forced-choice target questions that focused on the character's name, preferences, memories, knowledge, and category membership after the transformation. A sixth question concerned the preferences of the character 1 year after the transformation. Each question had two possible answers, one corresponding to human characteristics and the other corresponding to animal characteristics. For the example story above about Molly and the wizard, the first five questions were as follows:

- ''If you asked her who she was, would she say, 'I'm Molly' or 'I'm a seal'?''
- ''Does she think about eating fish or does she think about eating macaroni and cheese?''
- ''When she remembers being little, does she remember being a little girl or a little seal?''
- ''Does she know how to catch fish or does she know how to build sandcastles?''
- ''What is she now really, a girl or a seal?''

The sixth question required the experimenter to first explain some further background, as follows:

> Remember the spell the wizard cast on Molly in the story? The spell turned Molly's brain into the brain of a seal. Her body was still the same, but her brain turned into the brain of a seal. Molly was six years old when the wizard cast the spell on her. The spell lasted for a long time. So by the time Molly turned seven years old, the spell was still not broken. Molly had lived on for a whole year with the brain of a seal inside her own body. So, after living for a whole year with the brain of a seal inside her own body, would Molly think about eating fish or would she think about eating macaroni and cheese?

Following the first story, each participant heard a second story about a different character (a boy or girl) who underwent a different magical transformation. If the first story had concerned the transformation of the protagonist's brain (but not his or her body), the second story involved the transformation of his or her body (but not brain). The same set of questions was then asked, modified only to match the details of the story plot (character's name, food preferences, skills, category, memory, and preferences over time). Which story type came first was counterbalanced across children, and we ensured that each child heard two different stories (i.e., with different characters) at the follow-up visit than he or she had heard at the first visit.

Administration and coding of children's responses. At both of the time points, each participating child took time out of regular instruction to work individually with an experimenter who recorded his or her verbal responses to all of the questions using a digital audio recorder. The experimenter also noted children's responses on a coding sheet. Following each school visit, a researcher who was blind to study objectives (and who did not attend the visit) listened to each participant's audio recording in the laboratory and coded the child's responses to each question into a spreadsheet. The data from this blind coder were used in the statistical analyses. Given that the questions administered were almost all forced choice, the coding of children's responses was straightforward. Reliability between the coding during the visit and the offline coding of children's responses was extremely high (99.7% agreement, as computed for 20% of the sample).

Details of the intervention. At the first time point, after the conclusion of the one-on-one question/answer sessions between the experimenter and each participant, all participants listened to the designated lesson, which took place in their regular classroom. In the experimental lesson, lasting about 20 min, the experimenters first engaged the participants in an interactive activity involving the senses, and they discussed the function of different sense organs. The experimenters then showed the children a model of the brain while reading excerpts from two nonfiction books for young children: *Your Brain* by Terri DeGezelle (2002) and *Your Brain* by Anita Ganeri (2003). Throughout the lesson the experimenters emphasized how the brain and sense organs are connected via nerves and how the brain is involved in sensory activities. Toward the close of the lesson there was a discussion of how to keep one's brain healthy, and participants were given the opportunity to examine the model brain more closely and to ask questions about the lesson material. More complete details of the experimental intervention are presented in the Appendix.

In the control lesson, which also lasted around 20 min, the experimenters asked the participants to volunteer anything that they already knew about honeybees. Then the experimenters read the nonfiction book *Busy Buzzy Bee* by Karen Wallace and the fiction book *The Honeybee and the Robber* by Eric Carle. While reading the books the experimenters elaborated on the book content and asked the children relevant questions. At the conclusion of both books children were given the opportunity to play with a honeybee hand puppet and to ask questions about the lesson material.

Results

To address our central question about the role of the brain in sensory activities and feeling states we computed a composite score for each child that reflected the number of correct (affirmative) answers to the five questions relating to the brain's involvement in sensory activities and "feeling happy." A repeated measures ANOVA revealed a significant main effect of test time, $F(1, 127) = 14.51, p < .01$, whereby there were more correct responses at the second (follow-up) time point. There was also a significant interaction effect between time and intervention group, $F(1, 127) = 11.55$, $p < .001$, such that those in the experimental (brain intervention) group scored significantly higher on the composite score than those in the control group at Time 2, $t(127) = 2.33$, $p < .05$, with no significant difference between the groups at Time 1, $t(127) = -0.82$, $p = .41$. In addition, paired t tests showed a significant increase between the two time points in the mean score for the experimental group, $t(66) = -4.04$, $p < .001$, but no change

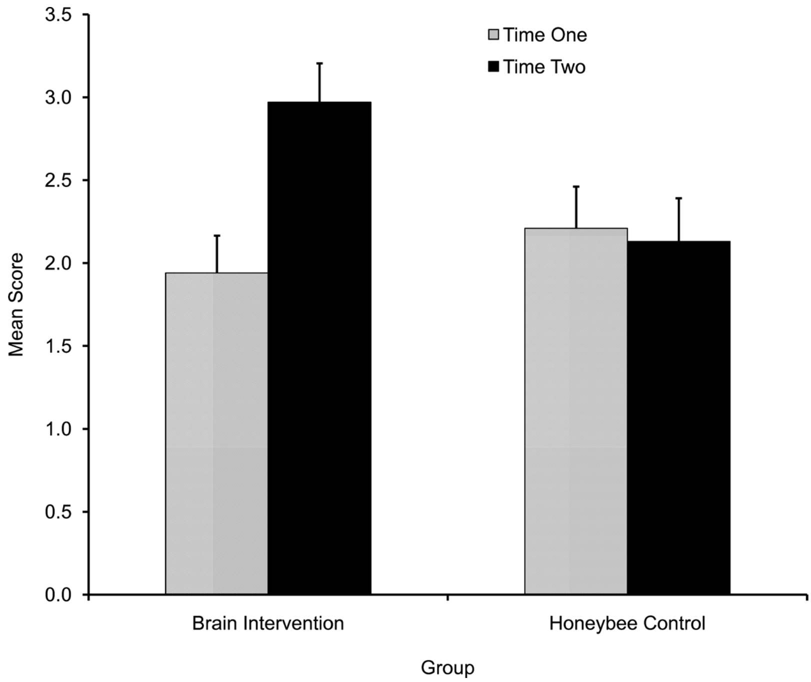

FIGURE 2 Mean score (out of 5) for each group in Study 2 at both time points on the composite measure of the brain's involvement in everyday activities and feelings. Error bars indicate +1 *SE*. $n = 67$ for the intervention group, $n = 62$ for the control group.

in the mean score for the control group, $t(61) = 0.41$, $p = .67$. The mean scores on the composite measure for the two groups at both time points are shown in Figure 2.

We next examined children's responses to the set of questions concerning other general brain knowledge, including the involvement of the brain in thinking and remembering. A preliminary series of nonparametric tests suggested that there were no group differences in terms of the ability to correctly answer each of the five general brain knowledge questions at either time point. Table 3 shows the percentage of correct responses for each of these questions, collapsed across the experimental and control groups at Time 1 and Time 2.

TABLE 3
Percentage of Correct Responses Across the Entire Sample to the General Brain Knowledge Questions in Study 2 ($n = 129$)

Question (correct response)	*Time 1*	*Time 2*
What part of your body do you use to think? (Brain)	82.2	90.7
Do you need a brain to remember? (Yes)	99.2	98.4
If you could see inside someone's head, would you be able to see their brain? (Yes)	47.3	57.4
Does a rock have a brain? (No)	97.7	100
Does a tree have a brain? (No)	98.4	97.7

In order to analyze the responses to the questions from the vignettes about body/brain transformations we computed how many children's responses ''followed the brain'' for each story type. For example, one particular set of stories concerned the central character's body being transformed into an animal's body but retaining his or her original brain. For this story type, when participants were asked what the transformed character's name was, giving the child's name (e.g., Molly) or giving the child's preferences (e.g., for macaroni and cheese) rather than those of the animal in the story were counted as responses in which the brain of the transformed character (but not the body) primarily determined the identity of that character. In the other story type the protagonist's brain was replaced by that of an animal while his or her body remained that of a child. For a child's response to follow the brain his or her answers about this story type would be that the thoughts, memories, or skills of the transformed character would be those of the animal whose brain the individual now had. Table 4 shows the percentage of such responses (i.e., those that followed the brain) at each time point for both the experimental and control groups.

Following Corriveau et al. (2005), we computed a composite score that reflected each child's propensity to emphasize the role of the brain in determining the characteristics of the transformed character. This composite was made by summing each child's responses that followed the brain for the name, preference, memory, and knowledge questions. Given that each child heard two stories at each time point, scores on this measure for any given child could range between 0 and 8. Responses to the questions regarding category and time were not included in this composite score because they appeared to tap into different notions of personal identity and did not follow the same general pattern of responses following the brain as the other four question types (see Table 4). For the category question, children's responses appeared to be driven primarily by the outward appearance of the transformed character. Interpretation of the time question, which was an exploratory later addition to the study, was complicated by uneven cell sizes between groups and is not discussed further here.

For the composite score, a repeated measures ANOVA showed a significant main effect of test time, $F(1,\ 119) = 13.30$, $p < .001$, with more responses following the brain at Time 2

TABLE 4
Percentage of Children's Responses in Study 2 That "Followed the Brain"

	Brain intervention group		*Honeybee control group*	
Characteristic	*Time 1*	*Time 2*	*Time 1*	*Time 2*
Name	44.2	53.4	45.6	62.6
Preference	60.0	67.5	61.3	72.6
Memory	55.0	62.5	62.1	66.1
Knowledge	56.7	60.9	63.7	70.2
Category	28.6	25.9	23.4	15.3
Time	63.0	63.2	54.1	72.6

Note. Results are shown for each group (intervention/control) at the two study time points. Responses that followed the brain indicated that the characteristics of the transformed protagonist reflected the kind of brain that he or she had as a result of the transformation (child's brain vs. animal's brain) rather than the kind of body (child's vs. animal's) that he or she now had. $n = 60$ for the intervention group and $n = 62$ for the control group for all cells except the time question for the intervention group, for which $n = 50$.

($M = 5.15$, $SD = 2.16$) than at Time 1 ($M = 4.50$, $SD = 1.71$). There was no main effect of group and no significant interaction effect between time and group, $F(1, 119) = 0.23$, *ns* ($M = 4.32$, $SD = 1.80$, for the experimental intervention group at Time 1; $M = 4.67$, $SD = 1.61$, for the control group at Time 1; $M = 4.88$, $SD = 2.28$, for the experimental intervention group at Time 2; and $M = 5.41$, $SD = 2.02$, for the control group at Time 2).

DISCUSSION

The results of Study 1 provide a contemporary replication of prior findings of general differences between older and younger children's views of brain function. Although almost 30 years have passed since the original work of Johnson and Wellman (1982), our findings are similar in that younger children appear to see the brain as an entity solely used for thinking. Given that young children receive little formal instruction about the brain, and they cannot observe their own brain, they have to rely on informal testimony from others to support their emerging concepts of brain function (Gelman, 2009). In this respect it is possible that the way that adults talk about the senses with young children (e.g., ''your eyes are for seeing'') reinforces a folk psychological concept of the brain as only for thinking.

In contrast to younger children, children 9 years of age and older in Study 1 were much more likely to affirm that the brain is involved in everyday activities and feelings. This finding is in line with the AAAS standards (AAAS, 1993, 2009), which suggest that around the third grade children start to understand the body in terms of systems of organs that work together. It is possible that this more sophisticated understanding is developed or enhanced through exposure to science curricula in middle school, when students are first exposed to specific instruction on human biology.

In combination with prior work, the results of Study 1 suggest that in the elementary school years young children have a relatively limited view of the brain's involvement in sensory activities and feeling states. In our second study we were interested in whether exposing first graders to a brief educational intervention in which they were taught about the diversity of brain functions would broaden their conceptualization of the brain's involvement in everyday activities. We focused particularly on the relation of the brain to the senses, in part because the results of Study 1 confirmed that sensation is a process for which young children appear to be particularly insistent of the brain's lack of involvement.

In our second study we were also interested in whether the promotion of the involvement of the brain in sensory activities may also impact young children's thinking in the domain of personal identity. As noted earlier, prior work has suggested that in the early elementary years children are adopting the notion that personal and psychological identity is determined, to a large extent, by the kind of brain one has rather than by the body in which this brain resides (Corriveau et al., 2005; Gottfried et al., 1999; Johnson, 1990).

Our predictions in Study 2 were twofold. We first predicted that our intervention would be successful in increasing first graders' knowledge about the involvement of the brain in everyday sensory activities and feeling states. Given that the intervention was intended to indirectly emphasize the close relationship between brain function and bodily sense organs, we more speculatively hypothesized that it would work against a normative tendency for children to increasingly view the brain (but not the body) as the primary seat of personal identity. If so, children in the intervention group may be less likely than children in the control group to emphasize the importance of the brain alone in determining the maintenance of an individual's psychological characteristics. This hypothesis was based on a suggestion by Dalton and Bergenn (2007) that the conceptualization of the brain as a disembodied container for thoughts and memories could be ripe for modification as it begins to emerge over the early elementary years.

In line with the results of Study 1, our findings from Study 2 showed that first graders already have some basic knowledge of the brain, primarily concerning its role in mental acts such as thinking and remembering. Children in our study were also aware that inanimate objects such as rocks and trees do not have brains. However, consistent with our findings in Study 1, the first graders in Study 2 were still relatively unsure of the brain's involvement in everyday sensory activities or feeling states. We were able to modify this picture somewhat with our classroom intervention, with children who were given the lesson on brain function having a better understanding of the brain's involvement in everyday sensory activities and feeling states compared with those children who were given a control lesson about an unrelated topic (honeybees). Our first prediction for Study 2 was therefore supported: Even our brief intervention with first graders was enough to improve their knowledge of brain functioning as assessed 3 weeks later. After our intervention, first-grade children were better able to confirm that the brain is involved in activities such as seeing and smelling. It is tempting to suggest that this reflects an early grasp of the concept that a combination of different bodily organs (e.g., the brain and the nose) can work together to carry out a given activity, although further work is needed before this can be assumed.

Our second prediction—concerning the possible impact of the intervention on children's understanding of the role of the brain in determining personal identity—was not supported. The brain and body transformation questions based on the story vignettes in Study 2 showed a general testing effect whereby across the whole sample, children at the follow-up visit tended to express that the characteristics of the transformed characters followed the brain. In other words, regardless of the body of the transformed character, children showed an overall shift over the course of the study toward answers that associated the name, preferences, memory, and knowledge of the character with the type of brain (and not the kind of body) that he or she had acquired or retained as a result of the magical transformation. For instance, if the story involved the child's brain moving into the body of a pig, there was an increase across the study in children reporting that the resultant creature would be more like a child than a pig. If the story involved the child's body remaining the same but receiving a pig's brain, children increasingly reported that the creature would be more like a pig than a child. In terms of explaining this general shift in children's responses across the two time points, it is possible that by the second visit children may have been better able to process the information presented in these rather complex vignettes because they had heard similar stories at the first time point.

The overall effect of time on children's responses to the vignettes was independent of assignment to the experimental versus control group. Our somewhat speculative expectation was that the children in the neuroscience intervention group would be less likely than children in the control group to give responses that associated the physical continuity of the brain with the maintenance of psychological characteristics such as preferences, memory, and knowledge. However, it is possible that first-grade children cannot go beyond a rudimentary grasp of the connections of the brain with the bodily sense organs to a realization that brain function is therefore somewhat dependent on the nature of one's body. This may be because of inherent limitations in children's thinking at this age, or it may be that our transformation stories did not present enough of a contrast to bring out this rather abstract linkage. It is also possible that the nature of the stories and forced-choice questions that we asked were not really tapping into questions of personal identity in a naturalistic way (Gelman & Wellman, 1991). Finally, as noted earlier, this area of research is complicated by the fact that over the years that children are typically developing an understanding of the brain's wider involvement in everyday activities, they are also narrowing their conceptualizations of the brain as a container for thoughts, memories, and preferences. Further work could explore this interesting paradox in terms of the development of a ''folk neuropsychology'' (Rodriguez, 2006) and of children's developing conceptualizations of brain, mind, and body (Bloom, 2004).

In terms of limitations of the current studies, we note that there were a number of methodological issues that could be improved in future work, and thus the work presented here should be considered exploratory rather than definitive. One area for future improvement is the online survey methodology used in Study 1, although we also note that the results of this study are in broad agreement with prior work. One other key area for improvement concerns the difficulty in matching participating schools in Study 2. Although we endeavored to match schools based on geographic proximity, the experimental and control groups of children did differ in terms of their backgrounds. Although this is not ideal, this problem is somewhat offset by the lack of baseline (pretest) differences between the groups in the main dependent measures.

In conclusion, we return to our initial theme concerning the neglect of basic neuroscience material in the elementary curriculum. In part this neglect reflects a general underemphasis on science at the elementary level, with science-related material often being relegated to after-school sessions for young children (e.g., through offerings from Science Explorers or similar organizations). As noted at the outset of this paper, this partly reflects the unwavering focus on early math and literacy in contemporary elementary education, an emphasis that comes at the expense of other subjects. One other likely reason for this underemphasis is the lack of training in science for elementary school teachers (e.g., Cameron & Chudler, 2003). However, our second study demonstrated that basic aspects of brain function can be taught to children in the early elementary grades without requiring a great deal of specialized knowledge on the part of the instructor. Such material could easily be supplemented with information or activities drawn from online sources such as Neuroscience for Kids at the University of Washington website.

Our classroom intervention in Study 2 brain was very brief (20 min) and was only carried out on a single occasion. But the fact that children in the experimental group showed increased retention of information about brain function when tested 3 weeks later is promising for the development of more intensive approaches. If carried out consistently and reinforced by adult conversation and supervision, exposing young children to information about the brain and its wider involvement in sensation and bodily functioning could have a number of implications. For example, if young children understand that the brain has essential links to all bodily functions, they may realize that it must be protected from harm through (for example) wearing a helmet when riding a bicycle, eating a healthy diet, or avoiding drug use. Indeed, this aspect was emphasized in the latter part of the experimental lesson (see the Appendix). Learning about the brain may also help children to better understand and accept those people in their lives who are affected by neurological disorders (Cameron & Chudler, 2003). Finally, educational material about the brain could also be embedded within the larger context of learning about the human body and the functioning of various other major organ systems (e.g., the heart, the lungs). Given that young children can only learn about these unobservable systems through informal testimony (Gelman, 2009), early exposure to basic concepts about the ''insides'' of the body may provide a useful foundation for when children encounter more in-depth material on human and animal biology in the middle school years.

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APPENDIX

Details of the Experimental Classroom Intervention

Three experimenters delivered the lesson on the brain, which lasted around 20 min and began with engaging the children in an activity in which they reflected upon each of their five senses. First one experimenter clapped her hands, and the children were asked to do the same. The experimenter then asked, ''Do you hear the loud sound of us clapping?'' While she touched the sleeve of her shirt, the children were asked to do the same, and the experimenter asked, ''Do you feel how soft your shirt is?'' The experimenter pointed to the classroom teacher, the students did the same, and then the experimenter asked, ''Do you see your teacher over there?'' Next children were asked to consider the following questions: ''Which parts of our body were we using when we were listening to each other clapping?'' ''Which parts of our body were we using when we were touching our shirts?'' ''Which parts of our body were we using when we were looking at your teacher?'' ''Which part of our body would we use to taste a really yummy ice cream cone?'' and finally, ''Which part of our body would we use to smell some pretty flowers that grow outside?''

The experimenters then shared with the participants what the five senses are as well as what the associated sense organs are. Examples were offered, such as, ''A special part of our body that we use to taste our food is our tongue'' and ''The special parts of our body that we use to hear a beautiful song are our ears.'' The children were then asked to volunteer answers to the following questions: ''Who can name one of the five senses?'' and ''Who can name a body part that we use to experience our senses?''

The experimenters then introduced the brain by telling the children that their brain is ''the big boss,'' and they asked everyone to point to where their brain is. One experimenter displayed a model of the brain for the students to look at while she explained that the brain is closely related to what happens in the rest of the body. Children were asked to volunteer some ideas about activities that our brains help us to do every day. The connection between the brain and the five senses was then introduced, along with a repetition of what the five senses and the sense organs are. Children were told that as part of its role in the senses, the brain sends and receives messages from all parts of the body. As part of this, the experimenter reinforced the fact that ''messages'' travel back and forth between the brain and the body (including the sense organs).

An experimenter then read various sections from a nonfiction children's book about the brain (DeGezelle, 2002), beginning with an introduction to how the brain, spinal cord, and nerves make up the nervous system. This section explains that the brain and body send messages back and forth through the spinal cord and/or nerves. The concept of the structure and function of the nervous system was reinforced by showing an illustration of the nervous system from the book as well as pointing to where the brain and spinal cord are in the body.

The following book section then further focused on the relation between the brain and the senses. For instance, the following example from the book was given:

> . . . your nerves tell you if water is too hot. The nerves send a message to the brain. The brain tells muscles in your arm and hand to pull back. Messages travel instantly between your brain and other parts of your body. (DeGezelle, 2002, p. 11)

The experimenters provided additional examples of how the brain relates to the senses and asked students to volunteer other examples. Children were reminded that the brain and body ''work together as a team'' to help sense the world around us. This part of the lesson was supplemented by illustrations from Ganeri (2003) showing another simple diagram of the nervous system inside the body.

An experimenter then read the section ''Thinking and Feeling'' from DeGezelle (2002), which centers around how the brain allows one to think, remember things, make decisions, store memories, and experience emotions. There was then a brief review of what had been learned so far, followed by a reading of the section ''A Healthy Brain,'' which describes how to keep one's brain healthy: by staying away from drugs, wearing a helmet when skating or riding a bicycle, exercising the brain by doing puzzles or thinking games, getting plenty of sleep, and eating healthy food.

Toward the close of the lesson children were asked to volunteer some of the important things they learned that their brain helps them do, and the experimenters reiterated or elaborated on any issues covered in the lesson as necessary. They emphasized that because our brain is responsible for so many things that we do, that it is important for us to keep it as healthy as we can. The participants were allowed to volunteer ways that they could keep their brain healthy. After a brief final review, the experimenters gave the children an opportunity to ask questions and to further examine the model brain.