MIND, BRAIN, AND EDUCATION

Brain-Based Learning and Educational Neuroscience: Boundary Work

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ABSTRACT— Much attention has been given to "bridging the gap" between neuroscience and educational practice. In order to gain better understanding of the nature of this gap and of possibilities to enable the linking process, we have taken a boundary perspective on these two fields and the brain-based learning approach, focusing on boundary-spanning actors, boundary objects, and boundary work. In 26 semistructured interviews, neuroscientists and education professionals were asked about their perceptions in regard to the gap between science and practice and the role they play in creating, managing, and disrupting this boundary. Neuroscientists and education professionals often hold conflicting views and expectations of both brain-based learning and of each other. This leads us to argue that there are increased prospects for a neuroscientifically informed learning practice if science and practice work together as equal stakeholders in developing and implementing neuroscience research.

In past years, many articles have focused on the "gap" between neuroscience and the practice of education and on attempts to build connections between these two fields (see e.g., Ansari, Coch, & De Smedt, 2011; Hruby, 2012; Koch, Timmerman, Peiffer, & Laurienti, 2013; Samuels, 2009). A number of different reasons are given for the difficulties in bridging the two fields, including unrealistic expectations about the direct impact of educational neuroscience (Ansari, De Smedt, & Grabner, 2011); the fundamental nature of neuroscientific research (Bruer, 1997); language barriers, poor communication between scientific researchers and educational practitioners (Pickering & Howard-Jones, 2007); the philosophical and epistemological differences between research and practice; the history of education as a field somewhat impermeable to scientific influence (Samuels, 2009); and the view that the way that children should be taught should not follow from neurophysiological insight because that does not take into account moral and political arguments (Davis, 2004).

Beauchamp and Beauchamp (2013) have taken a closer look at the boundary between the disciplines of neuroscience and education science in order to "further thinking about what the connection between neuroscience and education might mean and what issues might need to be addressed to smooth the linking process" (p. 54), In an education science context, Akkerman and Bakker (2011) have defined *boundaries* as the "sociocultural difference leading to discontinuity in action or interaction" (p. 135). We argue that it is important not only to focus on the boundary between different scientific disciplines, but to also gain insight into the boundary of science and educational *practice*, especially considering the developments that have been taking place with regard to brain-based learning in recent years. Even though bridging the gap appears to be difficult, we see a worldwide trend of initiatives aiming to do just that, many of them commercial. For example, different types of educational neuroscience products (or practices) include "brain-training," representing a $300 million-a-year industry in the United States alone (Hurley, 2012), professional development workshops and conferences, educational materials such as curricula and teaching guides, and psychoeducational assessment (Busso & Pollack, 2014).

The Netherlands have also witnessed the publication and popularization of books by neuroscientists like Dick Swaab (2010) and Eveline Crone (2011) and the organization of conventions with neuroscientists about the brain for

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teachers, inclusive of the symposia *Brain and Learning* and *The Adolescent Brain* in 2012 at the PABO[1] and Fontys Academy, respectively. "Brain-based learning" or "brain-friendly learning" are terms that have become very familiar within education institutes in The Netherlands. Although scholars have critiqued developments like this, arguing that the scientific foundation of most brain-based learning methods is weak and leads to the formation of pervasive "neuromyths" (see e.g., Goswami, 2006; Lindell & Kidd, 2011), there may also be some promise for educational neuroscience in this development. The field of education is clearly interested in the brain, and steps are being taken to integrate scientific knowledge within practice.

Beauchamp and Beauchamp (2013) analyzed the disciplines of neuro- and education science in a literature study addressing boundary-spanning actors, boundary language, and boundary objects. *Boundary actors*, people who span the boundary between neuroscience and education, could come from both fields, but could also be relative outsiders or hybrid professionals who step in as brokers between the two fields (Beauchamp & Beauchamp, 2013). The concept of *boundary language* was used by Beauchamp and Beauchamp (2013) to describe references to both language being an issue in crossing the boundary as well as the (metaphorical) language used by actors to describe or refer to the boundary (Beauchamp & Beauchamp, 2013). The term *boundary object* describes interfaces key to developing and maintaining coherence across social worlds (Star & Griesemer, 1989). In their work, Beauchamp and Beauchamp (2013) use the concept to describe concrete tools, entities, artifacts, or models that connect the education science and neuroscience disciplines, such as research schools proposed by Fischer (2009) and Samuels (2009). Furthermore, they describe frameworks facilitating the link between the scientific disciplines, such as the one proposed by Howard-Jones (2008). In this article, we interpret boundary objects more broadly and in line with Wenger (2002), distinguishing between boundary objects that are material artifacts, processes, and discourses. In this interpretation, the language used by actors would be seen as a boundary object.

Although these concepts provide us with tools to describe the boundary, more emphasis could be placed on the role actors themselves have in shaping the boundary they are part of. In order to further the understanding of this oft-described gap, we expand on Beauchamp and Beauchamp's (2013) boundary perspective by adding the notion of *boundary work*, a term coined by Gieryn (1983). Gieryn understands boundary work as the discursive practices used by scientists to safeguard autonomy, prestige, and control of resources, with which a boundary between science and nonscience is *created*. With regard to educational neuroscience, this would refer to instances where neuroscientists or educators contribute to the gap and the barriers between the two fields. In response to Gieryn's work, Zietsma and Lawrence (2010) identify two additional types of boundary work discussed in literature regarding boundaries in institutional change and stability. One is the *managing* of cross-boundary connections using boundary-spanning actors and boundary objects. This occurs when action is undertaken to bridge the gap between neuroscience and education. The final type of boundary work identified by Zietsma and Lawrence (2010) is the breaching of boundaries when science and practice are integrated. We argue that it is important to view boundary work also in light of opportunities for bridging the gap, thereby establishing a boundary not purely as a condition for separation between fields, but also as a possible interface for exchange and inclusion.

To the best of our knowledge, previous research has not yet dealt with the way in which the boundary between neuroscience research and education practice is socially constructed. In this article, we therefore aim to provide insight into this boundary in The Netherlands, with a specific focus on brain-based learning. We aim to describe both what is happening at this boundary, and ways in which actors negotiate and form the boundary between these fields. To this end, we analyze the role of people at the boundary, the function of boundary objects in the form of artifacts, shared processes, and discourses, and the performing of boundary work, with which boundaries are created, managed or breached.

METHODS

In this qualitative study, we conducted semistructured interviews with 14 neuroscientists and 12 education professionals involved with education and the brain, between 2010 and 2013. The scientists included were all engaged in neuroscientific research into learning processes and some of them identified themselves as educational neuroscience researchers. We selected respondents using maximum variation sampling with respect to research groups and topics in order to gain insight into the variation of perceptions (the breadth and depth of different ideas). Therefore, we first mapped out which university departments in The Netherlands are leading in educational neuroscience research, and then approached the heads of department for an interview. The interviewees came from 10 different universities. All but one respondent were senior scientists; a PhD student was included at the suggestion of the head of her department.

The education professionals selected had a specific interest in neuroscience and the brain, and already played an intermediary role between neuroscience and education practice, as we wanted to know more about their past

experiences with the translation of this type of knowledge. These interviewees were active in the field of education at different levels, for example on the board of directors of both secondary or tertiary education institutes, as organizers of projects aimed at the integration of brain-based learning in schools, or as developers of brain-based training for teachers, without a direct link to an education institution. We identified nine interviewees through an Internet search for Dutch equivalents of "brain-based learning," and continued our search using a snowball method, asking both neuroscientists and other education professionals for other potential interviewees. After ensuring we had appropriate representation of the different kinds of education professionals involved with brain-based learning, we continued with interviews until no new data were collected in two consecutive interviews.

Respondents were interviewed in their work place and each interview lasted about 1 hr. All interviews were open and semistructured, using the same topic list for both groups. Topics that were discussed included (a) the interviewee's personal background, (b) their characterization and definition of brain-based learning, (c) their experience with the translation from science to practice, (d) their experience with and characterization of the gap between the two fields, and (e) the barriers and opportunities they identified for bridging this gap. To ensure validity of data gathered, a summary of all interviews was sent to the interviewees and they were invited to a science-society dialogue session. The analysis of these results was also discussed during this dialogue session, which was attended by, among others, two of the neuroscientists and two of the education professionals who were interviewed.

All interviews were recorded after informed consent, transcribed in full and analyzed using Atlas.ti. The first author started with an inductive content analysis of the transcripts through open coding that stayed close to the text. At that point, the boundary perspective had not yet been taken. Rather, this perspective emerged during discussions about the data with the second author. At that point, the work of Beauchamp and Beauchamp (2013) was taken as a starting point for the subsequent thematic coding and the translation of the initial codes into broader categories (boundary people, boundary objects, and boundary language). This analysis was then specified further using Wenger's (2002) categorization of boundary objects and extended with the concept of boundary work as conceptualized by Gieryn (1983) and Zietsma and Lawrence (2010), as this made it possible to capture the influence of actors on the boundary. This whole process was iterative, the authors going back and forth between the initial open coding and the subsequent broader categorizations. The quotes used in this article are all translated from Dutch.

RESULTS

We sequentially describe the boundary people, boundary objects, and boundary work encountered during the interviews.

Boundary People

All our interviewees can be described as (potential) boundary-spanning actors. In this section, we describe who they are, what they do in relation to neuroscience and education, and how they became interested in working at this boundary. The neuroscientists were engaged in some way with learning, varying from research to brain development in adolescence, to mapping interaction of brain areas during certain learning processes, to neuroimaging research for learning disorders such as attention deficit hyperactivity disorder (ADHD). It was argued by some neuroscientists that applications within the educational practice speak to them because they themselves are also stakeholders in education, having had the experience of going to school themselves, having children at school and being involved in the education of university students. Within our group of interviewees, this inspired individual valorization initiatives corresponding to the writing of books or giving lectures in which new neuroscience insights are explained and applied to education.

The education professionals in this study were diverse in their backgrounds, current activities, and the way they engaged with educational neuroscience. Many were standing on the crossroads of different practices, combining, for example, a job as an educator with running a small company. Most interviewees mentioned that media coverage of the learning brain piqued their curiosity about this topic. Educational neuroscience was perceived to be an interesting new perspective in relation to their personal experiences in practice and appeared like a good approach to more evidence-based education. This was deemed important in light of mixed successes of previous educational reforms in The Netherlands. In addition, some interviewees argued that the lack of concrete applications for these insights motivated them to fill this gap and actively pursue an increased understanding of neuroscience. One of the education professionals interviewed explained that his engagement with educational neuroscience stems from a sense that it is important to anticipate questions coming from educational practice, in order to make an informed assessment of the potential of this information:

> We were enticed by all this news streaming about the brain, development, the learning brain. And we wanted to anticipate questions, also from the side of education. What should we do with all this? All these things are

> being claimed and named and it seems like a hype. Commercialized, so to speak. And we wanted to get a feeling for this and decide for ourselves what to do with it. (educational professional)

This interest has encouraged education professionals to become involved in different types of activities in which scientific findings are integrated in practice. For example, some respondents were involved in brain-related training or courses. At one school a clinical psychologist had been employed to scan scientific literature and share this with the school board, and steps were taken to incorporate this in teaching practice. In another case, the school established their own "brain and learning" group, appointing certain teachers as "frontrunners" to bring inspiring scientific concepts to the discussion table, in order to further deliberate with other teachers and the school board on how these ideas could be worked with in practice.

Boundary Objects

In our analysis of boundary objects, or interfaces between science and practice, we make a distinction between artifacts, shared processes, and discourse.

Artifacts

First, we identified boundary objects that are material and concrete, such as books about brain-based learning, brain-based learning training programs, scientific articles, and newsletters that researchers send to schools about their research and results. In our interviewees' descriptions of the way they were introduced to the books, articles, and learning theories, key to their teaching method or training, we encountered a degree of randomness. Most of these education professionals did not have the time or money to invest in a complete overview of research findings, as a result the insights that were applied in practice were mostly the ones that had somehow been brought to their attention, through colleagues, a seminar they attended, or through the popular media.

Functional magnetic resonance imaging (fMRI) images can also be considered to be boundary objects, because not only do neuroscientists use them to locate brain activity, they also find their way into the popular media. Many scientists interviewed were concerned about the focus of newspaper or magazine articles on brain images. One educational neuroscientist argued the following:

> I will look up a picture for you. Look, if you see this … we are becoming totally swamped by these. You would almost say, the researchers are right because it looks so fancy, but in fact it's like a white doctor's coat in laundry detergent commercials, the allure and the seduction of fMRI research, and mainly the way in which results are being presented. (…) I think that a very small number of people know what this way of representation means. (educational neuroscientist)

Some interviewees, like this neuroscientist, implied they were afraid that the way in which neuroscience has been represented in the media gives the wrong impression of the meaning of the colored patterns shown in fMRI images:

> Learning is not only the wearing out of existing pathways, no, new pathways are also being formed, with a preference for certain brain structures. But that is not being told. Rather it's [like this]: look at this, a picture of the brain, something lights up like flashlight so to speak. (neuroscientist)

This interviewee argued that this could potentially give the impression that function is fixed in the structure of the brain, like a "modern phrenology." Other neuroscientists also argued that locating disorders in the brain makes them more "real," but also releases parents and teachers from responsibility with regard to learning disorders. All interviewed neuroscientists stressed that the brain is plastic and flexible. Moreover, many argued that it is not the brain but the behavior of the child that should be understood, changed, or modulated with regard to education and learning. They feared this message does not come across clearly. Interestingly, none of the education professionals included fMRI or the possibility of viewing the brain in their definition of a brain-based learning approach.

Shared Processes

Boundary objects can also be shared processes or organizational procedures, such as teacher conferences about brain-based learning or neuroscience research programs. Most education professionals that had been to a conference mentioned that the conferences were not a bidirectional interface: neuroscientists shared research findings and answered questions without engaging further with the educational practice. Structured cooperation between research and practice took place only to a limited degree, mostly at the level of academic hospitals, testing clinical applications, and of research projects conducted at schools, in which some of the education professionals had been involved. According to one of the neuroscientists, most schools are happy to participate in research studies because they realize that "they can contribute to important research." However, another neuroscientist noted that some schools are beginning to complain that too much is being asked of them, especially in university towns.

One of the educational practitioners described how results from a scientific study conducted at his school were applied at that school:

> It was an enormous study about (…) carried out by researchers of the (…). Many very interesting things came out of it. And we read those results, and discuss them in teams, and then we see what we can use. [X] calls that low hanging fruit, what can you pick and consume? That is basically our strategy, it is quite ad hoc. (education professional)

However, none of the education professionals spoke of a durable relationship with the neuroscience practice. Some education professionals gave accounts of failed attempts to cooperate and promises that were not fulfilled. Small, short-term pilots were not considered to be sustainable because people revert to their old behavior after their initial enthusiasm has eroded and people who were not involved in the project do not feel committed to change their teaching methods. This was met with disappointment among some of the educational professionals, although one of the interviewees also explained that the meeting between science and practice during a research project gave a fresh impulse to the school to continue to find their own direction for brain-based learning.

Discourse

The third type of boundary object distinguished by Wenger (2002) is *discourse*, the existence of a common language allowing people to communicate and negotiate meanings across boundaries. Both parties frequently mentioned the issue of language as a barrier to educational neuroscience. Many education professionals explained that the way in which scientific articles are written makes it difficult for them to really engage with the results. In addition, some education professionals argued that, during dialogue, scientists make it hard for them to engage as an equal stakeholder by speaking in a language that excludes the participation of nonexperts.

A commonly heard phrase during the interviews with neuroscientists was that "the public and scientists just don't speak the same language." Almost all neuroscientists mentioned that research findings, especially data from fMRI studies, have to be "translated" with respect to brain processes otherwise they will not be correctly interpreted by outsiders. Translating this complex information without oversimplifying it was considered to be a difficult feat. Many of the neuroscientists argued that it was important to invest more in training researchers to be able to talk to stakeholders from education or to translate their articles into new articles written in "normal human language."

Several neuroscientists also mentioned that sometimes stakeholders think they are talking about the same object or concept when they actually mean different things. An example given was the neurocognition of memory or attention compared to memorizing or paying attention in class. Another example of this is the concept of *evidence*. One of the interviewed neuroscientists described how this word connotes something different in the language of science than in the language of practice:

> We have to be aware of the fact that on these two islands we speak two different languages. If you look at very simple terms that have to do with education, such as (…) the word *evidence*. Yes, for me as a scientist, evidence is something that is very quantitative, almost a statistical concept. But evidence in the practice of education has much more to do with interpretation and meaning (…). We have to be aware of this and try to reconcile these different languages. So that at least we are talking about the same thing. (educational neuroscientist)

Researchers frequently compared education to health care, a field that in their assumption was much more grounded in evidence-based interventions. They reasoned that in order for neuroscientific findings to contribute to more evidence-based education, they first need to be made applicable and then rigorously tested and fine-tuned in practice. However, the field of education research does not provide the right conditions for these large-scale and long-term studies to be carried out, as education research programs are always limited by budgets and time.

The education professionals all understood evidence very much in relation to their own, local practices. Many of these interviewees stressed how important it is to connect research results to local practice, because every classroom and every teacher is different. This is illustrated by one of the interviewees:

> So we want to work more evidence-based, to keep on having this check (…) How do I relate this to my own experience, what I see. And what are the effects of interventions that I do in education? We try to keep it very concrete, so to also keep on connecting the input of knowledge to our own observations. (education professional)

We argue that the concept of "brain-based learning" is also a boundary object because it is viewed differently from both sides of the boundary. During the interviews, we tried to find a definition of brain-based learning, to gain insight into where exactly the "brain" is in this approach and what makes it different from other types of learning. It appeared that

all education professionals and scientific researchers found it difficult to provide such a definition. The neuroscientists interviewed were mostly critical about brain-based learning, arguing that it is problematic to call an approach brain-based because, in the end, all research in learning has something to do with the brain. One of the neuroscientists argued:

> The point I want to make is that in the end, everything you do is neuro. Even if you train people with normal behavioral tasks, this will ultimately have an effect on the brain. (neuroscientist)

In this sense, brain-based learning creates a false illusion that it is different from, or more effective than, other types of evidence-based learning. In addition, some scientists mentioned that brain-training programs are not effective because they are basically a trial and error method. Brain research can lead to inspiration for possible applications in practice but teaching methods are not derived directly from insights into the brain. Some education professionals indeed argued that brain-based learning is actually just another term used for evidence-based education and encompasses all scientific research that has been conducted in the past 10–15 years. However, some others approached brain-based learning differently, arguing that the driving thought behind brain-based learning is the very realization that a person has a brain, an organ that you can train. According to them, this idea fundamentally changes things for people, because it gives them a better hold on their life and learning capacities.

Boundary Work

In this section, we focus on boundary work, or the creation, managing or disruption of boundaries in the narrative of neuroscientists and education professionals. The respondents identified numerous barriers to an educational neuroscience field and how these could be overcome; we argue that many of these issues come from a certain view on the demarcations between science and nonscience. Below, we describe two forms of boundary work. These relate to the way our interviewees describe the gap between the two different fields and the way in which researchers position themselves with respect to the boundary with education.

Boundary Work: Differences in the Description of the Boundary

When asked about the gap between neuroscience and educational practice, all respondents recognized its existence but described it in different ways, using particular metaphorical language, as also shown by Beauchamp and Beauchamp (2013). In the narrative of the researchers, the neuroscience field was described as an "island" that "spoke its own language" and it was said that intermediary parties should have knowledge of "both camps." Education professionals described the gap as a "distance" or a "large gap" between the neuroscience insights and their translation to daily activities of teachers in educational practice. One education professional involved in a project aimed at making a large Dutch educational neuroscience study accessible to the field of education, described how research and practice are basically just separate worlds, not having any interaction:

> So we made a summary you can say, and drew a number of statements from this summary. These statements were a bit provocative, and we presented them to some vocational training experts. (…) You can expect from these experts that they also orient themselves toward insights from other knowledge domains. So we presented them with these statements and they provided us with their opinion. And this in turn we presented to some neuroscientists. This was not easy, because they are so incredibly busy. (…) But this revealed how separate these worlds actually are. That if you want to say something sensible you really need to be deeply involved in it. (…) And I think it is important that both worlds need to be known somehow, but also that they acknowledge each other. (education professional)

One education professional described the research projects that came out of cooperation with universities as "islands," or "projects here and there," without doing something in an integrated way. With respect to the crossing of the boundary, some education professionals spoke about "a bridge to be built" and argued that it was important that the "two perspectives" are made clear.

When neuroscientists argue that there is a gap because research results are in need of "translation" to "normal human language," as discussed previously in this article, this can be seen as boundary work as defined by Gieryn (1983). This discourse, based on a specific perspective of the relation between research and practice, can be argued to contribute to the creation or reification of boundaries between research and practice. Using this narrative, most neuroscientists constructed neuroscience and education as two freestanding fields, between which information can be "transferred." However, who should be responsible for this translation of neuroscience findings to practice is not self-evident. Many researchers did not see it as their responsibility to do this translation because they are scientists, and thus not part of the education field. They described the goal of their research as providing insights into the structure and function of the brain, while "the application is for other people." In addition, many scientists also did not think that educational practitioners had the capacity to make neuroscience research relevant to education. One researcher argued as follows:

> Well, it's in question whether it's up to the researcher. As I said, you are not trained to be a jack-of-all-trades. You are trained to do good research. We don't have a school of journalism for nothing. (neuroscientist)

Within this rhetoric the two fields are placed far apart, necessitating others, "people invested in both sides" to fill the gap.

In contrast, most education professionals see the translation in a more bidirectional manner, as explained by the following interviewee:

> From the side of science I often get the impression that they think too easily about our trade. Teaching adolescents is a discipline that is underestimated. Everyone thinks they can join in the conversation and know what is interesting for us. In that sense the professionals at school should be taken more seriously. It really has to come from both sides. (education professional)

Many education professionals stressed the importance of the role of the teacher. Furthermore, some education professionals mentioned that the neuroscientists they encountered did not appear to have much knowledge of didactical theory. They considered it to be important to integrate these ideas into neuroscience research to improve the quality of the research, but also to give recognition to education professionals for their knowledge of educational practice. In order for teachers to take neuroscience seriously, they have to have the feeling that they are taken into account when new teaching methods are developed. For education practitioners, bridging the gap therefore means being part of the educational neuroscience dialogue, which goes two ways and starts from common ground.

However, an important issue mentioned by several interviewees of both science and practice is that educational culture in The Netherlands is particularly rigid because educators are tired of the many top-down changes the government has introduced. It was explained that young teachers coming straight from their training also switch to conservative teaching because that fits within the educational culture.

Boundary Work: Position to the Boundary

Some neuroscientists argued that the gap is not a matter of making the translation for laymen, but an issue related to the nascent state of the research field. Some researchers categorized their field of research as being very basic, their research findings having no direct implications for education (yet). Most neuroscientists were unwilling to make statements that were "insufficiently evidence based" and argue that it is important to be careful with making statements about implications for practice. Some were of the opinion that there is some danger in the quick translation of neuroscience, as this neuroscientist explains:

> I am just of the opinion that you cannot draw conclusions beyond your data. Because otherwise you create myths in society. People will do things that might not have the desired effect. Always when I am approached by the press I say that I am not the right person to talk to. (neuroscientist)

A few scientists mentioned that these myths could ultimately harm the image of neuroscience. Some neuroscientists argued that it is simply morally wrong to propose applications of research findings that have not been rigorously tested in practice.

Many scientists questioned the capacity of educational practice to understand, interpret, and be critical toward the meaning of neuroscientific findings, arguing that the level of knowledge in society about the brain is very limited. One neuroscientist argued that lay people are prone to draw the wrong conclusions from research findings because they are looking for easy explanations of certain phenomena:

> Not speaking each other's language is that you do not have the capacity to understand it. (…) You see something that you are not able to explain so you assume there is a logical explanation for it, which is what humans always do. (…) Causal relationships are established where there are none. (scientist)

This was considered undesirable because it can result in the categorization of behavior, which comes from a very fixed view on the development of the brain and can lead to labeling and stigmatization. Several neuroscientists mentioned that they thought it was important that the public at large, but especially education professionals, should learn to be more critical toward media reporting of neuroscientific insights and toward commercial brain-based training methods.

However, most education professionals acknowledged that the brain is being hyped and attracts a large degree of interest. Most of them mentioned that they too feel the need to be critical and that they realize that the brain-based learning approach is being hyped. For instance, one interviewee mentioned the following about the way neuroscience was being applied to education in some books:

> … it's often very hyped up and superficial. After two years I had enough of that (…) and I knew I would have to study it myself. (education professional)

At the same time, some education professionals admitted they make use of this attraction and try to motivate teachers this way:

> Once I mention the brain, everyone sits up straight. (education professional)

They consider brain-based learning brings a new perspective to teaching. Having the brain as a starting point gives education a way to understand why students act in a certain way. Although this is often not new knowledge for teachers, it gives them more insight into why certain teaching methods work and how they could approach individual students. Different education professionals described brain-based learning as "a tool" or an "instrument," to make things clear to people. One interviewee spoke about information "landing" when talking about the brain.

Regarding the fixed view on the brain as described above, education professionals realize that brain-based learning is a scary concept for many parents. This is illustrated in the following excerpt:

> Education professional: "But you have to carefully establish what brain-friendly education is, it's sort of a scary term you have to be careful with. Which scares people off."
>
> Interviewer: "What do you mean, it scares people off?"
>
> Education professional: "I have noticed that if you put too much emphasis on the brain, that you are interested in that, parents immediately see stickers with all kinds of wires on the heads of their children, guinea pig behavior. People don't want that, it sounds scary."

Their experience is that you have to be careful with this term, but that brain-based learning actually calls for increased flexibility toward children:

> Research has shown that there are gigantic variations in the tempo [of children's learning], and that we have to be very careful with that. So we look, we have installed that very consciously; we look whether a child is still in the right level in the second and third class. And we deal with that in a flexible way. (education professional)

Many of the education professionals were of the opinion that there is no harm in working with preliminary results, as they believed scientific results are always preliminary. They argued that scientific findings could serve as an inspiration to teachers. Being involved in a research project not only leads to increased knowledge about the brain but also makes it possible for teachers to be more critical toward their own practice and to the fixed routines embedded in their teaching styles. From this perspective, neuroscience could stimulate teachers to have a more inquisitive and reflexive attitude and enables them to make informed choices with respect to their own teaching approach. This is illustrated in the following quote by an interviewee, active in the specially installed "brain and learning" group within school:

> But scientists … We talked about it, if you are going to wait until the entire story is right, well, that would be never. Or you decide to see where we have the idea that things … like hey, that is something we recognize, we could do something with that. That's why we say, we don't assume that those things are in fact the truth, we always say: can this mean something for us? Let's do something with that, but always from an inquisitive stance. (…) It's being open for. (education professional)

Some interviewees mentioned that teachers are encouraged to conduct their own local experiments based on scientific theories, which was considered important because every practice, every classroom, all individual students and all teachers were described as different. This is an example of a boundary practice, where the teacher steps into the realm of the researcher.

DISCUSSION

In this article, we have not only described the boundary between neuroscience research and practice, but also ways in which actors themselves can influence the boundary. Our results indicate that on the one hand, a boundary perspective can cast an optimistic light on the gap between neuroscience and practice, as the boundary can be viewed as a place with plenty of activity, a place where the different parties involved can learn from each other. Many small bridges are being built, books are published for the lay public, research projects are conducted at schools in cooperation with educators, and conferences are organized where teachers develop a taste for neuroscience.

On the other hand, we have also seen that structured and long-term cooperation between neuroscientists and educators does not really take place. During the interviews, we recognized most of the barriers to bridging this gap identified in the literature and mentioned in our introduction, including the fundamental nature of neuroscience research, language and communication barriers, epistemological differences between research and practice, and a rigid educational culture. The boundary view used in this article can, however, provide a new perspective on these barriers and makes visible instances where neuroscientists and education professionals demarcate their own boundaries in the way they describe these barriers.

The dominant opinion among the neuroscientists is that the gap is predominantly about the language used. The solution they often provide—neuroscientists should better communicate their findings by involving communication experts—stems from a top-down approach to education and a classical view on science communication. Even though these scientists demonstrate an effort to bridge the gap, it can be argued that this solution actually exacerbates the difference between science and practice, reinforces the boundary between neuroscience and education, and thereby contributes to the gap. Most education professionals hold a different view and argue that scientists should be engaging more with the educational culture and interact more with educational practitioners in order to make the research more relevant to its practice. Education professionals do not speak "normal human language" as they have a professional expertise and language of their own, a point that needs to be recognized by neuroscientists. This different view on what bridging the boundary means is also reflected by the finding that in their description of the boundary, neuroscientists often spoke more about boundary objects, such as books or lectures, while education professionals talked most about shared processes, like being part of a research project.

Perhaps it is time to move beyond the notion of "bridge-building," as it comes with a connotation of two different islands, between which knowledge can be shipped back and forth. In our view, this way of knowledge dissemination might contribute to the fear neuroscientists expressed about their research finding its way into practice too quickly, as the science needs to be validated before it can be communicated. Interestingly, we have seen that education professionals argued that they evaluated the value of scientific findings on the basis of applicability and recognizability in practice. If neuroscience is to contribute to the complex and value-laden practice of education, it is time to find the middle road between scientific rigor and the more pragmatic approach of the field of education. Instead of bridging the gap in the translation and dissemination of knowledge, it might be useful to think of the integration of knowledge in terms of restructuring knowledge systems, in which different knowledge communities work together from the beginning in order to develop research questions that are the responsibility of all parties.

Recently, there have been a few scholars calling for more bidirectional research (Ansari, Coch, & De Smedt, 2011), or moving toward a *transdisciplinary* research practice (Beauchamp & Beauchamp, 2013; Samuels, 2009). Transdisciplinary research transcends the boundaries of academic disciplines (Giri, 2002), with scientists working together with practitioners to solve a complex, real-world problem (Klein, 2001). According to Pohl and Hirsch Hadorn (2007, p. 20) the aim of transdisciplinary research is:

> (a) to grasp the relevant complexity of a problem (b) to take into account the diversity of life-world and scientific perceptions of problems, (c) to link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good.

We feel that this aim connects well with the barriers identified in the interviews. This involves taking teachers seriously in order to better grasp how neuroscience can help them in their understanding of learning, investing in them to make the most of neuroscience in their own local practice.

In this study, the choice was made to interview neuroscientists and education professionals who we believe already played a role in creating, managing and/or disrupting the boundaries between neuroscience and education practice. We aimed for maximum variation sampling and achieved interview saturation. Therefore, it is expected that we have given an adequate representation of the breadth and depth of the perceptions of boundary-spanning actors. However, if we take a transdisciplinary perspective on breaching the gap, it would also be interesting to consult education scientists not involved in neuroimaging, as it can be argued they also play a role in brain-based learning, as well as other actors from educational practice, such as teachers, parents, and students. Further research could also focus more on possibilities for intermediaries outside of both fields, for example from the policy arena, to facilitate bidirectional interaction, as there were a number of structural barriers identified that would be difficult to resolve within research or practice itself.

However, the results of this study have also enabled us to recognize that transdisciplinary research is substantially different from the way research is done presently. We cannot expect scientists to make this radical shift overnight or by themselves. So where do we go from here? The suggestion to bring in middlemen (see e.g., Goswami, 2006) has by now become a familiar refrain in the neuroeducation literature. However, a more realistic way forward might be to not think of the middleman as a knowledge broker or translator, but more as a facilitator of knowledge integration. This means that there needs to be more boundary actors (or boundary-spanning teams) that are insiders of both neuroscience and education. A concrete suggestion for future research could be to divide large research projects into smaller learning communities of which scientists and educators are equal stakeholders, facilitated by a knowledge-integrating middleman. Besides creating a long-term direct interface between science and practice, this would stimulate the critical stance of teachers and other education professionals, providing them with the opportunity to apply knowledge about the brain in their own

practice, while simultaneously allowing neuroscientists to learn more about the day-to-day work that is being done at schools.

NOTES

1 PABO translates to "Pedagogical Academy for Primary Education."

REFERENCES

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, *81*(2), 132–169.

Ansari, D., Coch, D., & De Smedt, B. (2011). Connecting education and cognitive neuroscience: Where will the journey take us? *Educational Philosophy and Theory*, *43*(1), 37–42.

Ansari, D., De Smedt, B., & Grabner, R. H. (2011). Neuroeducation—A critical overview of an emerging field. *Neuroethics*, *5*(2), 105–117.

Beauchamp, C., & Beauchamp, M. H. (2013). Boundary as bridge: An analysis of the educational neuroscience literature from a boundary perspective. *Educational Psychology Review*, *25*(1), 47–67.

Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher*, *26*(8), 4–16.

Busso, D. S., & Pollack, C. (2014). No brain left behind: Consequences of neuroscience discourse for education. *Learning, Media and Technology*, 1–19. doi:10.1080/17439884.2014.908908

Crone, E. (2011). *Het puberende brein*. Amsterdam, The Netherlands: Prometheus.

Davis, A. (2004). The credentials of brain-based learning. *Journal of Philosophy of Education*, *38*(1), 21–36.

Fischer, K. W. (2009). Mind, brain, and education: Building a scientific groundwork for learning and teaching. *Mind, Brain, and Education*, *3*(1), 3–16.

Gieryn, T. F. (1983). Boundary-work and the demarcation of science from non-science: Strains and interests in professional ideologies of scientists. *American Sociological Review*, *48*, 781–795.

Giri, A. (2002). The calling of a creative transdisciplinarity. *Futures*, *34*(1), 103–115.

Goswami, U. (2006). Neuroscience and education: From research to practice? *Nature Reviews Neuroscience*, *7*, 406–413.

Howard-Jones, P. A. (2008). Philosophical challenges for researchers at the interface between neuroscience and education. *Journal of Philosophy of Education*, *42*, 361–380.

Hruby, G. G. (2012). Three requirements for justifying an educational neuroscience. *British Journal of Educational Psychology*, *82*(1), 1–23.

Hurley, D. (2012). A new kind of tutoring aims to make students smarter. *New York Times*. Available at http://www.nytimes.com/2012/11/04/education/edlife/a-new-kind-of-tutoring-aims-to-make-students-smarter.html

Klein, J. T. (2001). *Transdisciplinarity: Joint problem solving among science, technology, and society*. Basel, Switzerland: Birkhäuser Verlag.

Koch, K. R., Timmerman, L., Peiffer, A. M., & Laurienti, P. J. (2013). Convergence of two independent roads leads to collaboration between education and neuroscience. *Psychology in the Schools*, *50*, 577–588.

Lindell, A. K., & Kidd, E. (2011). Why right-brain teaching is half-witted: A critique of the misapplication of neuroscience to education. *Mind, Brain, and Education*, *5*(3), 121–127.

Pickering, S. J., & Howard-Jones, P. (2007). Educators' views on the role of neuroscience in education: Findings from a study of UK and international perspectives. *Mind, Brain, and Education*, *1*(3), 109–113.

Pohl, C., & Hirsch Hadorn, G. (2007). *Principles for designing transdisciplinary research*. Munich, Germany: Oekom.

Samuels, B. M. (2009). Can the differences between education and Neuroscience be overcome by mind, brain, and education? *Mind, Brain, and Education*, *3*(1), 45–55.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, *19*, 387–420.

Swaab, D. (2010). *Wij zijn ons brein*. Amsterdam, The Netherlands: Atlas-Contact.

Wenger, E. (2002). Communities of practice and social learning systems. In K. Starkey, S. Tempest, & A. McKinlay (Eds.), *How organizations learn: Managing the search for knowledge* (2nd ed., pp. 238–258). London, UK: Thomson Learning.

Zietsma, C., & Lawrence, T. B. (2010). Institutional work in the transformation of an organizational field: The interplay of boundary work and practice work. *Administrative Science Quarterly*, *55*(2), 189–221.