Peabody Journal of Education

ISSN: 0161-956X (Print) 1532-7930 (Online) Journal homepage: http://www.tandfonline.com/loi/hpje20

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PEABODY JOURNAL OF EDUCATION
2018, VOL. 93, NO. 3, 309–319
https://doi.org/10.1080/0161956X.2018.1449925

Reflections on Neuroscience in Teacher Education

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ABSTRACT
The majority of teacher preparation programs do not address neuroscience in their curricula. This is curious, as learning occurs in the brain in context and teachers fundamentally foster and facilitate learning. On the one hand, merging neuroscience knowledge into teacher training programs is fraught with challenges, such as reconciling how scientific evidence is viewed and used in education, overcoming neuromyths, acknowledging the lack of direct connection between laboratory findings and classroom practices, and coordinating across different levels of analysis in neuroscience and educational practice. On the other hand, there are marked benefits to such a merger, such as deepening pedagogical content knowledge from multiple perspectives; understanding neuroplasticity and its educational implications; recognizing the power of the environment to affect neurobiology, learning, and development; and contributing to engaged, reflective practice and informed inquiry in teaching. Particularly in terms of learning equity for students and the development of a learning education culture in teacher education programs, the benefits of including neuroscience knowledge in teacher training would seem to outweigh the challenges.

Introduction

As teachers fundamentally foster learning, and the brain is the "organ for learning" (Hart, 1983, p. 10), it seems reasonable that some study of the brain would be a component of teacher training programs. Yet most preparation programs do not address neuroscience (cf. Ansari & Coch, 2006; Coch, Michlovitz, Ansari, & Baird, 2009; Dubinsky, Roehrig, & Varma, 2013; Eisenhart & DeHaan, 2005; Hardiman, Rinne, Gregory, & Yarmolinskaya, 2012). Although there are potentially transformative connections between neuroscience and education (e.g., Organisation for Economic Co-operation and Development, 2007; The Royal Society, 2011), there are also serious caveats involved in making such connections (e.g., Bruer, 1997; Willingham, 2009). Below, I consider some of the challenges and benefits of connecting neuroscience and education in teacher preparation programs.

Challenges

The role of evidence

Neuroscience and education are two distinct (and vast) fields with separate histories, methods, and conceptual frameworks (e.g., Knox, 2016; Varma, McCandliss, & Schwartz, 2008). Neuroscience has always been primarily evidence-based, whereas education has begun moving toward an evidence basis more recently (e.g., Alberts, 2009; Slavin, 2002, 2003; Thomas & Pring, 2004). Using evidence

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in education requires scientific literacy (e.g., Stanovich & Stanovich, 2003). Thus, educators who are interested in understanding connections across neuroscience, learning, and teaching must be able to critically analyze research—but most have little training to do so (e.g., Ansari & Coch, 2006; Eisenhart & DeHaan, 2005). This is puzzling because many expert teachers do act essentially as researchers in their classrooms, systematically investigating both their teaching and their students' learning through action research and analysis of assessment data (e.g., Carter & Doyle, 1995; Nolen & Vander Putten, 2007; Postholm, 2009).

Nonetheless, it has been argued that the very consideration of scientific evidence is antithetical to education: A "tension between scientific and democratic control over educational practice and research … [imperils the] view that education is a thoroughly moral and political practice that requires continuous democratic contestation and deliberation" (Biesta, 2007, p. 1). This might suggest that issues of equity are especially ill-served by scientific perspectives on education. However, it has also been argued that making education-related research an accessible public resource can "extend Dewey's democratic theory of education while promoting a more deliberative democratic state" (Willinsky, 2002, p. 367). It has further been argued that science, "with its conception of publically verifiable knowledge, actually *democratizes* knowledge [because] [i]t frees practitioners and researchers from slavish dependence on authority … . Empirical science, by generating knowledge and moving it into the public domain, is a liberating force" (Stanovich & Stanovich, 2003, p. 10, italics in original). Thus, it seems that open access to relevant neuroscience evidence could be instantiated within teacher training programs without compromising the fundamentally democratic nature of public education. Indeed, "building cultures of evidence has the potential to be transformative in teacher education, but only if challenges related to sustainability, complexity, and balance are addressed" (Cochran-Smith & The Boston College Evidence Team, 2009, p. 458).

Neuromyths

Whether scientific evidence is a potentially powerful democratic tool in education and teacher training is a contentious issue; that scientific evidence can be misused and misconstrued is not. Neuroscience evidence might be especially attractive to educationalists because studies have shown that results including brain images are associated with increased believability (McCabe & Castel, 2008) and explanations including neuroscientific terms are judged more convincing (Weisberg, Keil, Goodstein, Rawson, & Gray, 2008; but cf. Hook & Farah, 2013). Although many "brain-based" educational products attempt to capitalize on the perceived cachet of neuroscience (e.g., Sylvan & Christodoulou, 2010), the evidence basis for these products is often highly questionable (e.g., Alferink & Farmer-Dougan, 2010; Bruer, 1999; Jorgenson, 2003). To be a critical consumer of such products and determine the legitimacy of claimed connections between neuroscience and education requires scientific literacy.

Many authors have also addressed the issue of neuromyths, mistaken beliefs about learning and teaching loosely based on neuroscience findings (e.g., Geake, 2008; Goswami, 2004, 2006; Howard-Jones, 2014; Organisation for Economic Co-operation and Development, 2007). One stunningly prevalent neuromyth is that students learn better when they receive information in their preferred learning style (e.g., visual, auditory, or kinesthetic); 93% to 97% of practicing teachers polled internationally believed that this was true (Dekker, Lee, Howard-Jones, & Jolles, 2012, p. 4; Howard-Jones, 2014, p. 818). It is not. Whereas it is true that different neural networks process visual, auditory, and kinesthetic information, these networks are not isolated units but rather interact instantaneously through massive cross-modal connectivity. In the intact brain in the real world (e.g., a child in a classroom), it is virtually impossible to exclusively process information in a single sensory modality. In addition to this misconstrual of neuroscientific evidence, there is currently little behavioral evidence in support of the claim that matching preferred learning style (if such exists) with teaching style—for example, teaching a "visual learner" with "visual methods"—results in better learning (e.g., Pashler, McDaniel, Rohrer, & Bjork, 2009). One factor contributing to widespread belief in this and other neuromyths may be a lack of opportunity for development of scientific literacy skills in teacher training programs (e.g., Mandinach, Friedman, & Gummer, 2015).

Direct connections

Underlying the learning styles neuromyth is the assumption that neuroscience findings can be applied directly to classroom practice, "from brain scan to lesson plan" (Howard-Jones, 2011; Murray, 2000). In many cases, this direct lab to classroom pipeline is an unworkable fallacy (e.g., Ansari, Coch, & De Smedt, 2011; Coch & Ansari, 2012; Howard-Jones, 2011), as much neuroscience research is descriptive rather than prescriptive (e.g., Christodoulou & Gaab, 2009). Yet overgeneralization with respect to classroom application of both behavioral and neuroscientific laboratory findings, without appropriate translation, is common (e.g., see Daniel, 2011; Klahr & Li, 2005). For example, the causal chain of reasoning from a basic neuroscience fact to a teaching method is often weak or nonexistent: Just because no two brains are exactly alike (established neuroscience fact), it does not follow logically that the Socratic method of teaching, which "delves into the personal relationship each person has with the question at hand" is "brain-based," "brain-compatible," or effective (e.g., Tokuhama-Espinosa, 2011, p. 102).

Levels of analysis

Generalization from lab result to classroom application is often not tenable in part because educational practice and neuroscience tend to operate at different levels of analysis. Referred to as "the vertical problem" (e.g., Willingham, 2009; Willingham & Lloyd, 2007), this presents challenges to integrating neuroscience into preparation programs. For example, although there is overlap between topics of interest to teachers and neuroscientists, the most useful levels of analysis for each may be different (e.g., Willingham & Lloyd, 2007): A neuroscientist might study phonological processing in reading single words, but not approaches to designing literacy centers for reading block. Indeed, many key issues in education, such as the politics of educational inequality (e.g., Fusarelli & Bass, 2015), are not directly addressable through neuroscience. And even when considering "the same learning phenomena, researchers focus on the basic component processes of complex cognitive abilities, whereas educators want to understand how formal instruction can best utilize and develop these cognitive abilities in pursuit of specific educational accomplishments" (Sheridan, Zinchenko, & Gardner, 2006, p. 265).

Consequently, the scope of the curriculum for teacher education would need to expand to include new levels of analysis (e.g., spanning from the neural basis of phonological processing to the politics of phonics instruction) in programs merging neuroscience with teacher training. At the start, such programs would likely involve both practitioners and researchers, necessitating a negotiation of vocabulary, methods, and values (e.g., Ansari & Coch, 2006; Ansari, Coch and De Smedt, 2011; Coch & Ansari, 2012; Dubinsky, Roehrig and Varma, 2013; Patrick, Anderman, Bruening, & Duffin, 2011; Vanderlinde & van Braak, 2010). Although challenging, this has the benefit of providing multiple sources of knowledge for preservice teachers on topics that span levels of analysis, and affords the possibility of sustained, interdisciplinary research–practice partnerships (e.g., Donovan, 2013; Snow, 2015). Such expansion would need to be accompanied by explicit recognition that one level of analysis does not inherently hold more or less value than another; rather, each adds to the understanding of a complex educational issue. For some time, there have been calls for just such new programs that would support the development of "neuroeducators" (e.g., Ansari & Coch, 2006; Ansari, De Smedt, & Grabner, 2012; Coch & Ansari, 2009; Cruickshank, 1981; Fuller & Glendening, 1985; Hardiman, Rinne, Gregory and Yarmolinskaya, 2012; Sheridan, Zinchenko and Gardner, 2006). Going forward, it is possible that these neuroeducators, raised in an integrated teacher training program, versed in both neuroscience and educational practice, and thinking transdisciplinarily as a habit of mind, could become the faculty of the future for teacher preparation programs.

Benefits

Pedagogical content knowledge

How might such an expansion of the curriculum to include neuroscience fit into existing conceptualizations of teacher training? Shulman (1987) proposed that pedagogical content knowledge was unique to teachers, at the intersection between what teachers know about teaching and what teachers know about their subject matter. From a more constructivist perspective, Cochran, DeRuiter, and King (1993) included knowledge about students' learning and learning environments in pedagogical content knowing. Neuroscience can contribute to the development of at least two of these four components of pedagogical content knowledge in preservice teachers: what teachers know about their subject matter and their students' learning.

Knowledge About Subject Matter. There are a number of content areas in which neuroscience evidence can support understanding beyond other forms of evidence or theory; for example, in reading and mathematical development (e.g., Ansari, De Smedt and Grabner, 2012; Blakemore & Frith, 2005; Dehaene, 1997, 2009; Goswami, 2004, 2006; Hinton, Fischer, & Glennon, 2012). As these areas have been reviewed extensively elsewhere, here I simply present a few examples from reading research. For instance, neuroimaging confirmed a phonological basis for dyslexia by showing different activation patterns in children with dyslexia and typical readers in a left temporoparietal region previously reliably identified as involved in phonological processing (e.g., Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000). Such findings discounted the theory that children with phonological dyslexia visually reverse letters as they read, illustrating that neuroscience can help to constrain educational theory (e.g., Byrnes & Fox, 1998). By extension, it would make little sense to use visually based approaches (e.g., colored lenses) to treat phonological dyslexia, and, indeed, there is little evidence that such approaches work to improve reading (e.g., Kriss & Evans, 2005; McIntosh & Ritchie, 2012). In contrast, neuroimaging has documented positive effects of intensive phonics (i.e., phonologically based) instruction for children with dyslexia, showing not only a shift toward normalization of activation in that left temporoparietal region but also gains to within normal limits on standardized reading measures with such instruction (e.g., Simos et al., 2002). Such research addresses both the outcome of instruction (product) and the mechanisms that underlie observed changes with instruction (process).

Moreover, differences in left temporoparietal activation patterns are present in the earliest stages of learning to read, in kindergarteners at risk for reading difficulties (e.g., Simos et al., 2002). In fact, differences in sound processing as measured by brain waves from 36-hour-old infants are predictive of reading skill (normal, poor, dyslexic) in the same children tested eight years later (Molfese, 2000). These findings, alone and in combination with other evidence, argue strongly for awareness, monitoring, and early identification and intervention, at least for children at risk for reading difficulties (e.g., those with a family history of dyslexia, Grigorenko, 2001), well before the start of formal schooling. Thus, neuroscience findings can contribute to public policy with respect to early intervention (e.g., Shonkoff & Levitt, 2010).

Knowledge About Students and Learning. Child development is an extraordinarily complex process, made up of many "interrelated and interdependent" processes across levels of analysis (e.g., Diamond, 2007). Interdisciplinary lenses, or multiple perspectives, are almost a necessity for understanding the dynamics of child and adolescent development and learning across the neural, cognitive, cultural, social, and emotional (et cetera) domains. Despite recommendations for teacher training programs to facilitate an understanding of learning and development across domains (e.g., Darling-Hammond & Bransford, 2005), many teacher training programs do not focus on developmental science (e.g., McDevitt & Ormrod, 2008). Indeed, a report from a national accrediting agency for teacher preparation programs in the United States concluded: "[I]f teachers are to address the increasingly diverse needs of all of the children that are entering today's classrooms, they need access to scientifically-based knowledge concerning student development and learning. Many educators, however—both teachers and administrators—have not been prepared to understand and apply advances in the developmental sciences in their schools" (Leibbrand & Watson, 2010, p. 1); the authors (p. 1, footnote 1) specifically noted that the term "developmental sciences" encompassed cognitive science and neuroscience. Thus, this report called for teacher education to include both learning education (i.e., how students learn) and teaching education (i.e., how to teach; currently, neuroscience has more to contribute to the former than to the latter), as well as explicate the relations between the two. Has this call been heeded? Sadly, a recent study conducted on the premise that "[a]t the heart of teacher preparation programs is the need for teacher candidates to learn about learning" concluded that "aspiring teachers are not being taught … [this] foundational knowledge" (Pomerance, Greenberg, & Walsh, 2016, p. 1).

Preservice teachers need not become developmental researchers or learning or cognitive scientists through their training. Rather, teacher preparation can provide the opportunity, support, and training for teacher candidates to become critical consumers of relevant research literature and to organize and use the knowledge gained in their practice. Cochran (1997) claimed that

> [t]eachers differ from scientists, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. In other words, an experienced science teacher's knowledge of science is organized from a *teaching* perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is organized from a *research* perspective and is used as a basis for developing new knowledge in the field. (¶ 5)

Although the developmental and learning research literature that preservice teachers are exposed to might be organized from a research perspective, it is possible in a well-planned teacher preparation program to help students restructure that evidence and reorganize it practically as useable knowledge for learning and teaching.

Neuroplasticity

The very notion of the ability to restructure knowledge provides an example of the plasticity of the human brain: Any input—all experience, including good teaching or bad—shifts the strength of connections between neurons, such that the brain is constantly changing. Plasticity is a core concept in neuroscience and is fundamental to learning and development (e.g., Dubinsky, Roehrig and Varma, 2013; Huttenlocher, 2002; The Royal Society, 2011). Understanding that all brains can and do change is foundational for both learning equity and a growth mind-set; the latter has been associated with higher achievement, more adaptive responses to challenge, and greater perseverance on learning tasks in numerous studies with students (e.g., Blackwell, Trzesniewski, & Dweck, 2007; Dweck, 1986, 2007, 2008; Paunesku et al., 2015; Rattan, Savani, Chugh, & Dweck, 2015). Whereas modest surveys have shown that a majority of in-service and preservice teachers in the United States have a growth mind-set, believing that intelligence is not fixed and that effort and practice make a difference for learning (e.g., Gutshall, 2013; Jones, Bryant, Snyder, & Malone, 2012; Lynott & Woolfolk, 1994), teachers without a growth mind-set could (unintentionally) demotivate students to learn (e.g., Rattan, Good, & Dweck, 2012). Thus, actively supporting neuroplasticity-based growth mind-set beliefs in preservice teacher preparation is a potentially powerful leverage point for learning and teaching.

Brain and environment interact

Neuroplasticity makes clear that the environment affects brain development, and vice versa. In terms of learning equity in the United States, one of the most salient examples of the influence the environment has on development is the achievement or opportunity gap related to socioeconomic status (SES): Children from poorer families tend to show poorer academic achievement than children from wealthier families, a gap which widened 30%–40% from 1976 to 2001 (e.g., Reardon, 2011, 2013; Sirin, 2005; Willingham, 2012). SES has been linked to neurocognitive functioning: Socioeconomic context shapes neural pathways involved in some skills (e.g., language, socioemotional processing, memory, attention, and other executive functions) differently in children from lower as compared to higher SES backgrounds (e.g., Farah et al., 2006; Hackman & Farah, 2009; Hackman, Farah, & Meaney, 2010; Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Nelson & Sheridan, 2011; Stevens, Lauinger, & Neville, 2009; Ursache & Noble, 2016). Leveraging this evidence, researchers have found that neural systems involved in such skills do show plasticity and are amenable to training, with at least short-term effects and perhaps greater effects in younger children (e.g., Blair & Raver, 2014; Bryck & Fisher, 2012; Green & Bavelier, 2003; Melby-Lervåg & Hulme, 2013; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Stevens, Fanning, Coch, Sanders, & Neville, 2008).

Recognizing the plasticity of these systems has naturally led to the empirical question of whether a well-designed curriculum targeting development of the very skills most at risk in young children growing up in poverty, such as cognitive or attentional control, could help these children better succeed academically and narrow the income-achievement gap. There is encouraging evidence that such training programs both effect neural change and have significant positive behavioral consequences (e.g., Blair & Raver, 2014; Diamond & Amso, 2008; Diamond, Barnett, Thomas, & Munro, 2007; Neville et al., 2013). Historically, success stories from more expansive (and expensive) early educational intervention programs confirm that some academic effects of poverty can be ameliorated; for example, participation in the Abecedarian Project or the Perry Preschool Program has had remarkable long-term educational and economic benefits (e.g., Belfield, Nores, Barnett, & Schweinhart, 2006; Campbell et al., 2012).

The effects of poverty, the mechanisms by which those effects operate, and the efficacy of interventions that target those mechanisms are core issues in educational equity. "If we do not find ways to reduce the growing inequality in education outcomes —between the rich and the poor—schools will no longer be the great equalizer we want them to be" (Reardon, 2013, p. 10). Integrating multiple perspectives informs a deeper understanding of the complexities of child development and learning in context, affording greater opportunity to disentangle and begin to address underlying causes of inequity (e.g., Blair & Raver, 2012). Neuroscience is not antithetical to social justice; on the contrary, it can provide further evidence to support righting injustices in preparation programs that train teachers-to-be from multiple perspectives.

Reflecting on practice

Indeed, Gardner (2009) has claimed that "educators ought to be able to think about educational issues from a number of points of view," stating that education is neither a discipline nor a profession, but rather "*a terrain for taking multiple perspectives*" (p. 69, original emphasis). Critically reflecting on one's own practice requires consideration from multiple perspectives, including research, theory, the evidence at hand, and pedagogical content knowledge (including neuroscience when relevant, e.g., Clarke, 1995; Copeland, Birmingham, de la Cruz, & Lewin, 1993; Etscheidt, Curran, & Sawyer, 2012; Rodgers, 2002). Reflective practice has been central to preparation programs for decades, yet its definition and impact remain in flux (e.g., Amobi, 2006; Clarà, 2015; Loughran, 2002; Redmond, 2014; Ward & McCotter, 2004). Hypothetically, in this iterative process of deep engagement and inquiry, teachers can learn from their own practice (e.g., Loughran, 2002) as well as others' (e.g., Teitel, 2009)—both using and building multilevel pedagogical content knowledge. Unfortunately, this is currently just a hypothesis: Scientific research on what works in teacher preparation, including the effects of training in reflective practice, is disturbingly sparse (e.g., National Research Council, 2010).

Conclusion

Over the past decade or so, there has been both increasing enthusiasm for and discussion about integrating neuroscience and education (e.g., Fischer et al., 2007; Pickering & Howard-Jones, 2007). Greater knowledge exchange, specifically in the context of teacher training, has been promoted by such diverse bodies as a national accreditation agency for teacher preparation programs in the United States (Leibbrand & Watson, 2010); The Royal Society in the United Kingdom (2011), which recommended that preparation programs "include a component of neuroscience relevant to educational issues" (p. 20); the international Society for Neuroscience (2009), which noted that "much is known about the brain and neurosciences that should be central to teacher preparation programs" (p. 4); and the Organisation for Economic Co-operation and Development (2007). Integrating neuroscience into teacher education programs provides another perspective on learning, development, and instruction. It bolsters teachers' scientific literacy and adds to teachers' "theoretical toolkit"—a view of "themselves as designers of experiences that ultimately change students' brains" (Dubinsky, Roehrig and Varma, 2013, p. 318). In some cases, it may add explanatory power as part of reflective practice and inquiry in terms of addressing underlying mechanisms that other levels of analysis cannot or do not address (e.g., Diamond & Amso, 2008). Overall, in the limited time offered in teacher preparation programs, neuroscience can play a modest but important role in building an evidence-based learning education culture.

While it is clear that neuroscience informs understanding of learning and development, going forward, it will be necessary to document the ways in which neuroscience knowledge affects both the practice of teachers and the educational experiences of their students. Those impacts must be considered in terms of what is valued: As part of the process of merging neuroscience knowledge into teacher preparation programs, "it is essential that educational values remain at the core" (Sheridan, Zinchenko & Gardner, 2006, p. 275). Through the lens of equity as an educational value, "[n]euroscience can help fulfill the mandate of public education, but only as a tool that is part of a broader conversation about what schools should strive to achieve for the millions of students who attend them" (Ferrari, 2011, p. 31). In the United States, priority education goals include ensuring "that students have more effective teachers" and "equitable educational opportunities" (p. 5), and long-term goals include "better and more widespread use of data, research and evaluation, [and] evidence" (U.S. Department of Education, n.d., p. 9). Integrating neuroscience into teacher education programs, although challenging, could meaningfully contribute to meeting such educational goals for all students.

Acknowledgments

I am grateful to Michele Tine for comments on a previous draft and countless inspirational conversations. In the interest of full disclosure: The Dartmouth College administration closed the Dartmouth Teacher Education Program during the publication process for this manuscript.

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