How Many Brains Does It Take to Build a New Light: Knowledge Management Challenges of a Transdisciplinary Project

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ABSTRACT—The Organization for Economic Cooperation and Development's (OECD) Center for Educational Research and Innovation (CERI) carried out the *Learning Sciences and Brain Research* project (1999–2007) to investigate how neuroscience research can inform education policy and practice. This transdisciplinary project brought many challenges. Within the political community, participation in the project varied, with some countries resisting approval of the project altogether, in the beginning. In the neuroscientific community, participants struggled to represent their knowledge in a way that would be meaningful and relevant to educators. Within the educational community, response to the project varied, with many educational researchers resisting it for fear that neuroscience research might make their work obsolete. Achieving dialogue among these communities was even more challenging. One clear obstacle was that participants had difficulty recognizing tacit knowledge in their own field and making this knowledge explicit for partners in other fields. This article analyzes these challenges through a knowledge management framework.

INTRODUCTION

"If only we had known . . . " This phrase was often heard in the halls of the Organization for Economic Cooperation and Development's (OECD) Paris headquarters after its Center for Educational Research and Innovation (CERI) undertook a project that was far from typical for the OECD. The project—*Learning Sciences and Brain Research* (1999–2007)—aimed to use neuroscience research to shed new light on our understanding of learning and inform education policy and practice. Phase 1 (1999–2002) identified areas of brain research with relevance to education: literacy, numeracy, lifelong learning, and emotions (OECD, 2002).[1] Phase 2 (2002–2007) further explored these areas in an effort to identify implications for education policy and practice (OECD, 2007). The goal of the project was straightforward, but the process of achieving it was riddled with unexpected obstacles, false starts, and surprising twists and turns.

This article will provide an analysis of the major challenges we faced in this context, so that others who would like to embark on analogous transdisciplinary endeavors can learn from our experiences and avoid plunging into the same pitfalls and trekking down the same dead ends that we have already discovered. Neither the definition of learning, nor the successes and findings of our project, nor the value added of neuroscientific insights to our understanding of learning beyond what we already know from social or educational contexts, will be reviewed here—that information is contained in OECD/CERI's (2007) *Understanding the Brain: The Birth of a Learning Science*. Instead, this article will reveal the challenges we faced and analyze these challenges within a knowledge management framework.

WHY USE NEUROSCIENCE TO SHED NEW LIGHT ON EDUCATION?

Over the past few decades, there has been increasing political and public concern about students' academic achievement, and policy makers across OECD countries feel an urgent call

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to create reforms that can improve the quality and equity of education systems (OECD, 2000). With the rise of learning societies,[2] an increasing number of professions involve working with knowledge, which places high demands on education systems. At the turn of the century, breakthroughs in neuroscience brought brain research to the center of research on learning (Fischer et al., 2007; Hinton, Miyamoto, & della Chiesa, 2008), and education policy makers are looking to this new research to shed new light on critical issues in education policies and practices (OECD, 2007). However, what may seem like a crystal-clear connection quickly becomes murky when mixed with politics, culture, history, and ethics.

Over the course of the project, we held many international conferences to encourage communication between experts in relevant disciplines, promote knowledge transfer,[3] and inspire new research. Our hope was that these communications would generate new knowledge, eventually conspiring to create a new transdisciplinary learning science (Koizumi, 1999).

TRANSDISCIPLINARITY

In a given system (or within a given discipline), new knowledge is generated by combining internal knowledge (specific to this discipline) with external knowledge (coming from other fields) and making tacit knowledge explicit (Al-Laham, 2003).[4] Creating new knowledge involves combining isolated knowledge assets synergistically to produce new capacities, ideas, or processes that existed neither internally nor externally (Probst, Rub, & Romhardt, 1997). Koizumi (1999) differentiates among interdisciplinarity, multidisciplinarity, and transdisciplinarity (Figure 1). In interdisciplinarity and multidisciplinarity, existing disciplines simply reciprocally influence each other, basically creating intersections in two dimensions. In transdisciplinarity, a new transdisciplinary field with its own conceptual structures is created through active cooperation and fusion of completely different disciplines. Transdisciplinarity is a dynamic concept whereby various disciplines are connected and ascend to a new discipline, giving rise to a three-dimensional shape. As Koizumi eloquently expressed, "[t]rans-disciplinarity emerges through a fusion and bridging of disciplines, not merely through the bundling of multiple disciplines" (p. 19). Transdisciplinary communication is extremely important but requires a concerted effort and commitment among experts of involved disciplines. However, academics tend to focus only on knowledge that is immediately relevant to their research (Heinze, 2003), which makes spontaneous combination of knowledge across fields rare.

In striving to create a transdisciplinary learning science in the *Learning Sciences and Brain Research* project, we encountered many interesting challenges, including cultural differences in acceptance, support, and active participation in the project; difficulties in attracting key education researchers due to

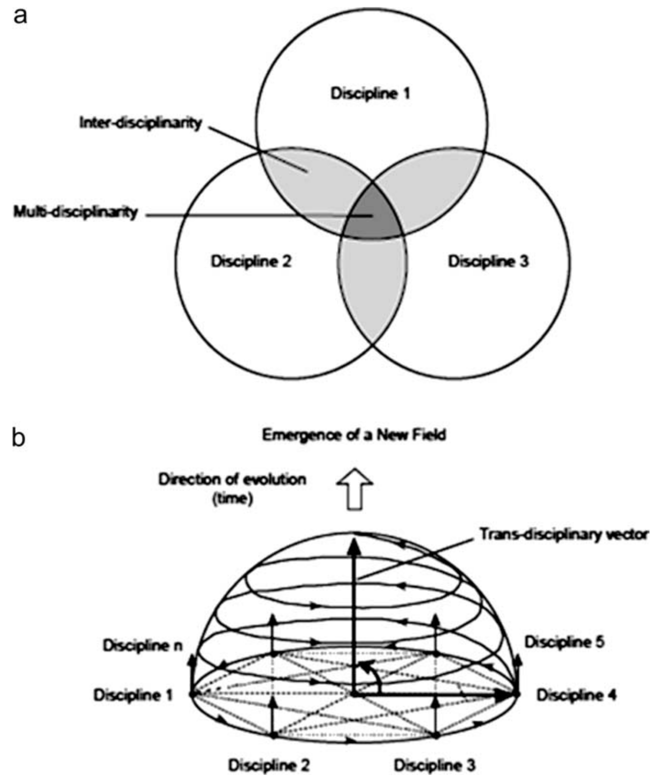

Fig. 1. The difference in the concepts or transdisciplinarity and interdisciplinarity (multidisciplinarity). (a) Interdisciplinarity (multidisciplinarity). (b) Transdisciplinarity. Source: Koizumi (1999).

political issues; and transdisciplinary communication difficulties. Koizumi's model proved to be a very useful tool to clarify the project's fundamental assumption, as it reflected both its initial structure (multidisciplinarity) and its desirable objective (transdisciplinarity). However, difficulties arose and the model could not provide solutions to analyze where these problems came from—these had to be found elsewhere. Nevertheless, we believe that the goal of creating a transdisciplinary learning science[5] is worth being pursued (In this issue, see Samuels' (2009) discussion of Mind, Brain, and Education as a potentially transdisciplinary field.).

A KNOWLEDGE MANAGEMENT VIEWPOINT

In knowledge management, the starting point is usually a problem or situation that can only be solved with new information. To create this knowledge, individuals need to actively connect information across fields, generate new information, and document the transfer of knowledge (Schneider, 1996; Wiater in Heinze, 2003). Individuals collaborate to produce, transmit, and apply new knowledge (Al-Laham, 2003; OECD, 2000).

Within knowledge management, a model uses the notion of transfer barriers to explain difficulties in exchanging knowledge across disciplinary boundaries (Schüppel, 1996). Transfer barriers hinder complete knowledge transfer and involve two dimensions: individual/collective and structural/political–cultural. In the first case, the person or group with the knowledge only provides part of the knowledge potential. In the second case, problems arise through issues of responsibility and personal interests that impede knowledge transfer (e.g., in organizations or business culture).

Individual barriers affect knowledge transfer between individuals and lead to a less-than-optimal use of the knowledge base. Collective barriers affect knowledge transfer between groups of individuals or organizations and lead to a less-than-optimal use of the knowledge base of a group or organization. Structural barriers impede knowledge transfer within an organization due to specific structural circumstances within the organization. Last, political–cultural barriers, which arise from established doctrines and restrictions of an organization (learned through cultural socialization), can hinder knowledge transfer (Schüppel, 1996). These dimensions can be put together in a matrix, creating four categories of transfer barriers (see Table 1). This framework is very useful for analyzing many of the challenges we faced during the course of the project.

WANTED: A COMMON LANGUAGE

Representations of definitions and concepts often vary greatly across fields. Even though we expected diverse representations between neuroscientists and educators, we largely underestimated the extent to which the representations would vary. We quickly discovered that a common language was needed with concepts defined that would be acceptable to both parties and understood in the same sense to make the knowledge of both fields accessible and understandable for all (Heinze, 2003). For instance, learning is a clear and fundamental area of overlap between brain research and education, but learning is a highly complex process and its definitions vary depending on the context and perspective. In fact, definitions used by neuroscientists and educational researchers differ quite significantly from each other, which poses major challenges for dialogue between the two communities. For example, Koizumi (2003) defines learning from a neuroscientific perspective as "a process by which the brain reacts to stimuli by making neuronal connections that act as an information processing circuit and provide information storage." In contrast, Coffield (2005), an educational researcher, proposes that learning refers to "significant changes in capability, understanding, attitudes, or values by individuals, groups, organizations, or society."[6] The term "knowledge" also lacks a common definition across fields (Al-Laham, 2003). This could be because the epistemological interest of each discipline defines the semantics and structure of a concept (Romhardt, 1998).

At first, we thought that creating a common language could solve communication problems across fields. Over time, however, it became clear that the problem was much deeper than a simple terminological discrepancy and that a common expression would not lead to a common representation. Knowledge can be connected across fields by linking symbols that represent partially overlapping concepts (Heinze, 2003). However, it is difficult to disentangle nonoverlapping aspects of concepts from overlapping aspects, leading to misunderstandings. Moreover, not all core concepts in different fields have overlapping aspects. Creating a common language is necessary, but far from sufficient, for creating a transdisciplinary science.

AN OVERAMBITIOUS PROJECT?

Creating a transdisciplinary learning science was a (perhaps overambitious) goal of our project. We hoped that neuroscientists and educators could not only exchange understandings but also actually collaborate to create new understandings enriched by both perspectives. This kind of cooperation supports progress in both fields by enabling experts to see new aspects of problems in their field[7] and recognize external issues of relevance to their field.[8] For example, neuroscientists began to consider questions with relevance to education in their research, which both expanded the neuroscience knowledge base in directions that may not have been pursued

Table 1
Transfer Barriers (Adapted From Schüppel, 1996)

Barriers	*Structural*	*Political–cultural*
Individual	• Emotional–motivational activation • Individuality and attachment to the past • Capacities of perception, processing, and learning • Wrong knowledge ("Verbildung") • Intrapsychic conflicts	• Role constraints/coercion • Rules of participation and differences in point of view • Belief in specific causal relationships
Collective	• Defensive routines • Conflicts of cooperation • Specialization	• Inhibition due to myths, tradition, and "groupthink" • Overemphasis of a common (disciplinary) culture

otherwise and enriched educators' understanding of problems in their field by shedding new light on them.

The acceptance and support of our project by the education ministries as well as the interest and active participation of researchers varied greatly and in interesting ways.

CHALLENGES

Challenges With the Policy Community

At first, it was difficult to predict what would result from our project, and if the investment (including financial, organization efforts, energy, and time) would be worthwhile, which led to interesting differences in the acceptance and support of the project by the education ministries. The cultural background of the political stakeholders played an important role. It quickly became clear that Japan and the United States were leaders in taking risks of this nature, with Europe (Finland, Spain, and the United Kingdom being exceptions) following cautiously behind. Most European countries wanted to see evidence that the project would yield useful results before accepting and supporting (including financially) the project and thus only joined slowly as the project gained momentum (della Chiesa & Christoph, 2003). At its inception in 1999, the project had only five supporting countries, including Japan, the United States, Finland, Spain, and the United Kingdom, but by 2002, 25 countries actively participated. Some countries resisted almost until the end, primarily because they were afraid that hard science might suddenly supplant traditional social sciences as reference disciplines for education (this concern was clearly voiced in countries like France and Sweden, for instance).

Knowledge communication involves exchanging, sharing, transmitting, and cross-linking knowledge (Heinze, 2003) in conferences, networks, publications, or social interaction among members of different groups. However, when representations are not shared, communication is difficult, as those participating in a communicative situation should express their ideas, intentions, and feelings openly and try to identify their assumptions and consider them potentially modifiable. For intercultural communication, this is an even greater challenge than for communication in general, as the readiness to communicate first has to be established and the capacities are more complex to achieve. All communication takes place under the ideal of a possible consensus (Heinze, 2003). A mixture of three of the four boxes of Table 1 come into play here: collective–structural, individual-political-cultural, and collective-political-cultural.

Challenges With the Neuroscience Community

Communication between specialized fields is important to enable knowledge transfer. However, the transfer of expertise between neuroscience and education is difficult, and three conditions are essential for optimal communication to take place: (a) Experts must be willing and able to share knowledge with those outside their field rather than just their peers.[9] (b) Experts need to adapt their "language" and content to the audience, in order to make their knowledge comprehensible to lay addressees (OECD, 2000). In general, participants of different nationalities from the same field had fewer difficulties understanding one another than participants of the same nationality from different fields. (c) Experts need to realize that in the long term connecting information across fields is advantageous for both others and themselves. As Wiater expressed, "knowledge communication only develops when people have the feeling that the exchange is a mutual give and take, a win-win-situation, and that it will be to their personal advantage" (Heinze, 2003, p. 90). At first, it was difficult to find participants for our project that met all three conditions—researchers who were doing good work in their field, were able to translate findings for lay people, and were committed to applying their research results to policy and practice.[10] Finding all these competences in a single person is quite rare.[11]

The reactions of the participants to these three conditions were very different. Brain researchers generally accepted invitations to meetings, seemingly prepared to share and receive new knowledge. However, most speakers were not very effective at communicating their knowledge because they rarely considered the audience and/or purpose. Accordingly, their presentations were too technical, cutting edge, and therefore mainly incomprehensible for lay people. Knowledge transfer was therefore not very successful at first. These difficulties seemed to stem not only from being confronted with an audience of nonspecialists in an unusual situation but also from a global incomprehension of the project and its goals.[12] Moreover, even when these were understood, they were sometimes in conflict with participants' professional goals. OECD/CERI held conferences to have neuroscientists communicate with educators. However, this objective was in competition with many neuroscientists' goals to exchange information with their peers, present their newest findings, and gain professional recognition. As a result, neuroscientists often provided masses of information relevant only to their peers, in effect drowning findings significant for educators in a flood of technical information. Relevant information for educators was generally only contained in the last slide (usually entitled "Conclusions") so that 20- or 30-min speeches could have been reduced to 2 or 3 min to promote a genuine exchange with the education community. Neuroscientists were often not willing to sacrifice their own professional goals to promote a more fruitful exchange with the education community.[13]

In terms of the knowledge management framework, the issues outlined above could essentially be described as individual–structural transfer barriers: Much of the neuroscientific community was characterized by a limited capacity of perception, processing, and learning. Although these problems partially faded over time, they were never completely resolved. The issues seemed closely tied to generational influences. Many of the 30- to 60-year-olds were primarily at conferences to prove their academic capacities to their peers (not only individual–structural but also collective–structural barriers like conflicts of cooperation occurred here). Scientists younger than 30 years, who usually do not yet have a fixed research orientation and could therefore direct their work according to new opportunities, were consequently much more flexible. The same applied to those who had already reached the end of their careers and no longer needed to impress anybody. Therefore, these two age groups could allow themselves to be more open to new ideas and applications (the only transfer barrier that could persist with these groups was the individual–cultural one, in the form of a field-specific worldview). Researchers of the middle age group were already specialized in a research framework and, given the rules of the game in academia, had a stronger need to be recognized by their peers in order to advance in their careers, which narrowed their flexibility and openness to new avenues. New developments like the OECD/CERI project came either too early or too late for them (individual–cultural restraints can also be noticed here: holding on to transmitted patterns of cause and effect that restrict the individual scope for development).

Neuroscientists and educators should recognize that collaboration is mutually beneficial. There is increasing consensus that even basic research should be useful for society.[14] It is therefore in the interest of neuroscientists to collaborate with educators because education will be a key sector in which applications of neuroscience are developed for practice. In conjunction, educators should be aware that collaborating with neuroscientists can support much-needed innovation and advancement in education (e.g., Program for International Student Assessment [PISA]; OECD, 2001, 2006).

Challenges With the Education Community

It was difficult to attract and maintain some educators' participation in our project as well. Unlike in the neuroscientific community, educators' patterns of engagement did not seem to be related to their progress in their career (age groups) but rather to function: researchers, policy makers, and practitioners.[15] The primary concern of researchers seemed to be that neuroscience would bring something new to their field that could endanger established knowledge and positions[16] (not only individual–structural barriers are active here but also collective–structural ones). Some educational researchers seemed to perceive neuroscience research as a potential threat to principles about learning established by social science research, which they had built their careers on. Furthermore, only a few education policy makers accepted invitations to our meetings, possibly because some of them were intimidated by arcane neuroscience and some of them saw a political danger related to the concerns of educational researchers. Namely, that education had thus far always used the social sciences (psychology, sociology, philosophy, etc.) as reference disciplines (OECD, 2000) and they feared that these disciplines would suddenly be neglected and replaced by neuroscience. This attitude created a collective–structural transfer barrier. Specifically, a fear (whether justified or not) that established power dynamics might be endangered by this new science entering other fields disrupted the transfer of knowledge.

This notion that neuroscience might invade the place of the other disciplines certainly reflected a misunderstanding of the project. The project team repeatedly stressed that neuroscience was intended to *inform* education, along with other disciplines. The goal was to develop a transdisciplinary field that would be a more powerful tool for addressing educational issues than any of the disciplines on their own. Perhaps, though, even this goal was perceived as dangerous because it could lead to new insights that contradict certain policies and practices (OECD, 2000).

Practitioners, in contrast to the other two groups, were generally delighted by the outcomes of our project (sometimes even a little too much[17]). This may be because teachers are the ones who are confronted with the problems of education systems on a daily basis and are therefore open to any recommendations that might help them cope with their daily struggles.

Overall, it quickly became obvious that there would be some resistance in the education community to using information about how the brain learns to inform education policy and practice. The reasons for this resistance are various—simple incomprehension, mental inertia, the categorical refusal to reconsider certain truths, corporate reflexes to defend acquired positions, or even staunch bureaucracy.[18] The obstacles to creating any transdisciplinary field are bound to be numerous because of the complex scientific, political, cultural, historical, and ethical issues related to knowledge management. Even if some constructive skepticism may be healthy, every innovative project finds itself at one point or another in the position of "K," seeking in vain to reach the Castle (Kafka, 1926).

To further complicate matters, neuroscience unintentionally generated a plethora of "neuromyths" founded on misunderstandings, false interpretations, or even (conscious or unconscious) distortions of research results. Over the past few years, a growing number of misconceptions (pseudo-approaches to how we learn) have started to circulate about the brain, including the myth of the first 3 years ("everything important about the brain is decided by age 3"), gender-related differences in the brain, and so forth. The existence of these neuromyths is sometimes used as ammunition against any use of neuroscience knowledge in education, which created further resistance to the project. Moreover, these neuromyths, which are incomplete, extrapolated beyond the evidence, or plain false, were entrenched in the minds of the public by the mass media,[19] which created yet another goal for the project: debunking neuromyths (OECD, 2007).

In addition to the neuromyth issues, a whole range of other, even more fundamental, ethical questions have arisen from the project, including the potential abuse of brain imaging, consumption by healthy individuals of substances that affect the brain, the risk of creating an excessively scientific education system, and so on. Many of these questions cannot be left to science only. It is critical that a well-informed public express their views on these issues because in democratic societies ethical questions need to be addressed through political debate.[20] Ensuring that this happens will not be easy, especially because the mass media in the present form are clearly not equipped to adequately, effectively, or honestly deal with such issues[21] (della Chiesa, 1993; Bourdieu, 1996).

WHERE ARE WE NOW?

The publication *Understanding the Brain: The Birth of a Learning Science* (OECD, 2007) explores how neuroscience can inform education policies and practices and promotes the development of a transdisciplinary learning science. It also establishes a transdisciplinary research agenda, which can support further collaboration across fields.[22]

It is still too early to say if the results of the *Learning Sciences and Brain Research* project will contribute to widespread improvement in education policies and practices. Although the knowledge has been disseminated, this does not guarantee its use: "There has to be a reason or incentive for a profession [. . . .] to be willing to adopt disseminated knowledge or practices, since more often than not adoption means giving up an existing practice, one that the new practice will displace. New knowledge and practices may be successfully disseminated to the target audience, but then for a range of reasons not adopted" (OECD, 2000, p. 40). In the case of our project, the recent blossoming of initiatives aimed at connecting neuroscience and education across Europe, Asia, and North America[23] gives us hope that, in spite of all of the obstacles the project faced, the emergence of a transdisciplinary learning science is underway.

WHERE TO GO FROM HERE?

A dialogue between the neuroscience community and the education community (including students and parents) is essential for continued progress.[24] This exchange of ideas should occur at an international level because every single learner is concerned, which means every human being (as there is no such thing as a brain that does not learn). Various initiatives are beginning to support this dialogue, and these efforts need to be continuous and permanent. Three kinds of initiatives that can further support this dialogue are: (a) Web sites and online forums (already being tried, like the former OECD/CERI Teacher's Forum, or others still to come); (b) regular journals and publications targeted at parents and teachers (and maybe students) to popularize neuroscientific findings without oversimplifying what remains an arcane, high-level, and cutting-edge science; and (c) the research schools movement (Hinton & Fischer, 2008). One of the key challenges we faced in our transdisciplinary project was that, before experts could exchange explicit knowledge across fields, they often needed to make tacit field-specific knowledge explicit. Experts found this task very challenging because it is difficult to identify tacit knowledge of a field when immersed in it (indeed, a fish does not know what water is). Another way to transfer tacit knowledge is to support long-term involvement across fields, which allows tacit knowledge to be shared through socialization. Research schools, which are living laboratories where researchers and practitioners work side by side to educate students and carry out research, provide the type of sustainable collaboration that can support transfer of tacit knowledge via socialization. In this context, tacit knowledge is shared through ongoing dialogue and becomes tacit for others. In this way, research schools can break down one of the key barriers to working across disciplines and are a powerful tool for supporting further transdisciplinary progress.

CONCLUSIONS

It is obvious that brain research alone will not solve every educational problem. In fact, as Klaus Luther (German CERI Governing Board member) said, "it is not going to solve any."[25] As a descriptive discipline, neuroscience is concerned with what is true or false (describing the world). Education, which is an intervention discipline, is foremost interested in what is feasible or not (changing the world[26]) and is thus better equipped to tackle issues of what policies and practices should be implemented. As science deals with true/false polarities, ethics deals with good/bad, politics with desirable/undesirable, and policy with efficient/inefficient oppositions. Although policy (what is efficient or not) derives directly from politics (what is considered desirable or not) and although politics, at least to some extent, directly depends on ethics (what is considered good or bad), there is no such mechanical cascading between the scientific field and any of the three other fields: ethics should not be replaced by science, especially as far as politics is concerned. What is feasible and what is not is asking, after taking ethical considerations into account, what policy is—or should be—all about (della Chiesa, 2008). History has shown how catastrophes follow when ethics is replaced by science, sound or not, and we certainly do not want to repeat such terrifying mistakes. Neuroscience can merely shed new light on issues that other disciplines have explored for centuries. Neuroscience should only be recognized for what it is: valuable new knowledge.

If educational arrangements were working so well that everybody was happy with them, there would be no reason to really look for new solutions. But because many people do not seem to be very satisfied with the outcomes of the present educational systems, it would be a terrible mistake, and an ethical mistake at that, not to consider this new set of information (Ajchenbaum-Boffety & Léna, 2008). Even if neither neuroscience, nor any other science, is designed to provide recommendations to policy makers and practitioners, the emerging "educational neuroscience" (term forged by Kurt Fischer, Founder and Director of Harvard Graduate School of Education's Mind, Brain and Education program) is generating valuable knowledge that can certainly inform, if not guide, educational policy and practice.

Despite the political, cultural, historical, and ethical challenges we faced, it is no longer acceptable to ignore neuroscience research in reflections on education nor to ignore the need to create transdisciplinary sciences more broadly, and we should continue to develop innovative solutions for tackling emerging challenges. The responsibility is huge. As the former CERI Governing Board Chair Sylvia Schmelkes del Valle so wisely expressed, "[w]e are not working for governments, we are working for our children and grandchildren."

NOTES

1 From the beginning, it was very useful to have world-renowned scientists (such as Michael Posner and Masao Ito) involved in the project, as this increased the project's credibility and made other researchers interested in becoming involved.

2 We deliberately avoid the expression "knowledge societies," as there is no such thing as a human society without knowledge. However, we believe that a specificity of our times, in this regard, is that we have to deal with "learning societies," which has not necessarily always been the case or at least not that clearly, and it certainly was not always mirrored at the individual level (i.e., a need for all citizens to be lifelong learners).

3 The very concept of "knowledge transfer" is still contested in some educational contexts, the very relevance of knowledge coming from other fields (here, specifically, from neuroscience) being questioned. Our position is that anyone who wishes to navigate using maps, which depict Earth as flat can do so, even if we doubt that anyone will go anywhere safely this way. If stakeholders are happy with the captain's job, that is, if taxpayers (parents, voters) are content with the outcomes of present educational arrangements, there is nothing wrong with maintaining outdated practices, at least from a cynical point of view. However, we should not forget that "the only good is knowledge, and the only evil is ignorance" (Socrates) and that "not to know is bad, but not to wish to know is worse" (African proverb).

4 "Explicit knowledge can be expressed in formal and systematic language and shared in the form of data, scientific formulae, specifications, manuals, etc. It can be processed, transmitted and stored relatively easily [it is codified or at least codifiable]. In contrast, tacit knowledge is highly personal and difficult to formalize [or even recognize]. Subjective insights, intuitions and hunches fall into this category of knowledge. Tacit knowledge is deeply rooted in action, procedures, routines, commitment, ideals, values and emotions. It 'indwells' in a comprehensive cognisance of the human mind and body. It is difficult to communicate tacit knowledge to others, since it is an analogue process that requires a kind of 'simultaneous processing.' Western epistemology has traditionally viewed knowledge as explicit. However, to understand the true nature of knowledge and knowledge creation, we need to recognize that tacit and explicit knowledge are complementary, and that both types of knowledge are essential to knowledge creation. Explicit knowledge without tacit insight quickly loses its meaning. Knowledge is created through interactions between tacit and explicit knowledge, rather than from tacit or explicit knowledge alone" (Nonaka, Toyama, & Konno, 2000, p. 7f.).

5 We are not referring to education in general here, but to the emerging "learning science," which is meant to inform education research, policy, and practice. Moreover, unlike others, we do not believe that education is already a transdisciplinary field, at least not in the sense we (after Hideaki Koizumi) give to this word. At best, it is multidisciplinary, and the traditional top-down approaches (cf. so-called "reference disciplines") only add to education's situation of "dependency." This is not what we are advocating here, of course.

6 The two perspectives/definitions, of course, are not only perfectly compatible, but in fact both must as a consequence be taken into account to get a fuller picture. However, the differences in terminology (and underlying representations) create misunderstandings and difficulties of communication.

7 As an example, over the years, it became clear that Anglo-Saxon research on dyslexia, focusing on decoding English, is not applicable to many other languages. Even

though much of the brain circuitry involved in reading is shared across languages, there are differences in decoding or word recognition strategies. In alphabetical languages, the "depth" of a language's orthography is crucial: a "deep" language (which maps graphemes onto phonemes, sounds onto letters, with a wide range of variability) such as English (e.g., the ending—ough, whose pronunciation varies widely: "rough," "through," "though," etc.) or French contrasts with "shallow" languages such as Finnish or Turkish (which consistently map one grapheme to one phoneme, making words easy to decipher and pronounceable only in one manner) (OECD, 2007, p. 15).

8 For example, many educators (and mainly teachers) willingly listened to neuroscientific findings and were largely willing to adopt them, in the hope that they would thus be able to improve teaching and learning in their classrooms.

9 There certainly is a question of social relevance or utility here and a matter of accountability of scientists to contribute to dealing with societal issues.

10 Being a bad or good (or even great), scientist does not necessarily make one a good popularizer of science. More importantly, to be a good popularizer one first needs to be a good scientist, and then add a range of other skills.

11 As soon as the difficulties of finding such persons had been identified, it became a new goal of the project to create a context from which people with such characteristics could emerge. In some cases, this was successful, as at the Harvard Graduate School of Education, which has started to train genuinely "transdisciplinarians" at the crossroads between neuroscience and education within the Mind, Brain, and Education program.

12 For example, a major neuroscientist who had participated in the project since the beginning expressed concerns after 5 years that "not enough science" (meaning basic research) was being conducted, which was from the beginning explicitly not a goal of the project.

13 For example, when the OECD/CERI *Learning Sciences and Brain Research* project manager reexplained the goals of the conferences at a meeting in El Escorial (March 2004), one of the scientists involved in the project since 1999 responded that, if neuroscientists were confined to presenting only information that was relevant for educators, no neuroscientist would come to the meetings anymore.

14 This of course does not (and should not) mean *immediate* relevance is needed, which would be paradoxical.

15 It is interesting to note that students and parents generally remained uninvolved in the project most of the time, which could be due to an organizational failure of the project on OECD's side or because these groups are not used to being part of strategic planning in education contexts, or both.

16 In order to integrate new knowledge, existing knowledge needs to be updated, completed, and, if necessary, unlearned (Al-Laham, 2003). "Innovation is a key outcome [of knowledge production] because it adds to knowledge and embodies its [. . .] value, but also entails destruction of obsolete [. . . .] knowledge" (OECD, 2000, p. 21).

17 Often, they too quickly accepted hypotheses and transformed them into "facts," thus contributing to the development of new neuromyths (see below), mostly without being aware of this.

18 As in the beginning, the project was rather marginal, unusual, and innovative within the OECD—"fun" in a way—it had a smooth start; but as soon as it started to be perceived as potentially "dangerous" problems arose. The project's promoters then had to fight on several fronts at the same time, because, with success, resistance was burgeoning in equal proportions all over the place. Especially within the OECD itself (and increasingly so when results enjoyed more and more recognition and visibility worldwide), the project encountered more and more obstacles. From an individual-political-cultural aspect, individuals—some staff members and some country committee representatives alike—showed resistance to the project (though the committees were a little less reluctant than the OECD Secretariat, which sometimes used the committees' expected reluctance as a pretext to be resistant themselves). This internal resistance came from a mix of mental inertia (people either unfamiliar with hard science and not ready to make the necessary effort to understand what the project was all about or simply bothered in their everyday routine by new questions), corporate reflexes (especially from those recently arrived from traditional academic educational research, who, maybe not without reasons, were afraid that their knowledge/positions/recognition within the academic world could suddenly be threatened by the newcomers), and of course the bureaucratic nightmares one faces in any large institution.

19 The collective-political-cultural barrier comes into play here, especially through the mass media (see below).

20 Of course, policy decisions do not necessarily mirror public opinion (Chomsky, 2006), and the willingness to improve educational outcomes (which, to a large extent, amounts to foster equity in educational settings; cf. PISA studies, OECD 2001–2006) is at least sometimes limited to mere incantations and declarations of good intentions from relevant authorities (Chomsky, 2006; della Chiesa, 1992).

21 Again, it is the mass media that play an important role here. As Bourdieu put it: journalists are most of all journalists, regardless of their potential background in other disciplines,

and they will always report on what is attractive and will attract a large audience, according to their specific lens. It's all about making the headlines, which sound scientific findings are unlikely to obtain . . . Moreover, information within the journalistic field is circular; journalists read each other and publish what they have read elsewhere. But where does the circle start?

22 A Web site was also established where neuroscientists and educators could engage in dialogue about learning. This Web site supported genuine reciprocal exchange across disciplinary boundaries. However, this deeply valuable exchange was often not codified and thus not recognized.

23 Harvard Graduate School of Education (Mind, Brain, and Education program) in the United States; The Research Institute of Science and Technology for Society of the Japan Science and Technology Agency in Japan; the Transfer Center for Neurosciences and Learning (Transferzentrum für Neurowissenschaften und Lernen, ZNL) in Germany, and so forth.

24 This was the first reason why the project was launched, under the vision and impulse of CERI's then head, Jarl Bengtsson, who had the remarkable intuition that neuroscience could be relevant for education. "High risk, but high potential pay-off" was the motto, sufficient to attract support from a few key countries, especially Finland (Reijo Laukkanen), Japan (Masayuki Inoue and Teiichi Sato), Spain (Francisco Lopez Ruperez), the United Kingdom (Richard Bartholomew and Christopher Brookes), and the United States (the National Science Foundation team Eric Hamilton, Eamonn Kelly, and Finnbar Sloane), to begin with; other countries, at first rather careful if not skeptical, quickly followed. Full support from Tom Alexander, then director of the Directorate for Education, Employment, Labor and Social Affairs, was also crucial to embark on such a venture.

25 However, neuroscience is already making significant contributions to educational policy and practice. On many issues, brain research simply, but valuably, reinforces existing knowledge and conclusions. Indeed, one of its most important contributions is to enable educators to move from correlation to causation—understanding the mechanisms behind relationships between interventions and outcomes. Moreover, neuroscience is generating new knowledge and opening up new avenues of inquiry.

26 One cannot help but think here of the famous quotation by Marx (1845) (Thesen über Feuerbach): "Die Philosophen haben die Welt nur verschieden interpretiert; es kommt darauf an, sie zu verändern" ("Philosophers have hitherto only interpreted the world in various ways; the point is to *change* it.").

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