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Educational Sciences: A Crossroad for Dialogue among Disciplines

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This article illustrates that due to the complexity of educational practices and of the educational system, their scientific study constitutes a crossroads for dialogue and possible conflicts among a variety of disciplines. The article focuses on school education. A first illustration shows how analyzing and improving classroom practices requires collaboration with and among different sub-disciplines of psychology. In the next section the recent domain of educational neuroscience is discussed as a crossroads of educational science, psychology and neuroscience. Thereafter, it is argued that research on mathematics education calls on the contribution of many disciplines such as mathematics, pedagogy, the psychology of cognition and math-related beliefs, and anthropology. The final example focuses on educational technology that requires interaction between educational science, psychology, computer science, economics, etc.

Introduction

Due to the complexity of education as a phenomenon, educational sciences/research constitute a crossroad for dialogue and possibly conflict among a variety of disciplines. This will be illustrated in relation to school education, but it also holds true for education in the family, for adult education, and for training and professional development in the business and corporate world.

School education takes place in the interaction between learners – individually and as a group – and a teacher in the social context of the classroom based on a curriculum. But classrooms are embedded in the physical, social and economic context of schools. And schools are part of a broader regional and/or national educational system that is managed and regulated by an educational administration and policy system. It is obvious that analyzing and improving school education at these three levels – the micro level of the class, the intermediate level of the school as an institution, and the macro level of the educational system – requires dialogue and interaction with a variety of disciplines, social sciences and humanities as well as sciences.

A first example relates to analyzing and improving learning and teaching in classrooms. Students of distinct ages differ in intellectual ability, and in this respect developmental psychology is an important source of information. But it is also important to take into account the research-based knowledge about how children and students learn in view of deciding about the appropriate teaching methods. Moreover, differential psychology shows that in a group of learners of the same age there are substantial differences in intellectual ability and learning potential; so one teaching approach does not fit all. And finally a classroom constitutes a social context and social psychology can help to disclose and understand the social relations and networks that may have an impact on learning and teaching in a class. In other words, analyzing and improving classroom practices requires collaboration with and among different sub-disciplines of psychology. But this example illustrates the need for interaction and working together within a family of disciplines. I will now turn to collaboration between domains that are less closely related.

Educational Neuroscience: A Crossroads of Education, Psychology and Neuroscience

In a report of The Royal Society of the UK published in 2011 it is said that:[1]

> Education is about enhancing learning and neuroscience is about understanding the mental processes involved in learning. This common ground suggests a future in which educational practice can be transformed by science, just as medical practice was transformed by science about a century ago.

In the Introduction of the recent book *Educational Neuroscience*, the goal of educational neuroscience is defined as finding out how students can be helped to realize their learning potentials and to make learning more effective for all students.[2] This is certainly a very ambitious objective. The path to these goals connects well to my first example above. Indeed, the collaboration between psychology and education in trying to make learning more effective constitutes the first step in the emergence of educational neuroscience. In the second step, which emerged in the late 1970s, cognitive neuroscience was created as a result of the collaboration between neuroscience and cognitive psychology, and focused on unraveling the biological substrates underlying cognitive activities, especially the neural substrates of mental processes. This joint venture quite soon led to addressing, in step three, issues that are relevant for education, more specifically studying the neural basis of reading and mathematics, and their deficiencies (dyslexia and dyscalculia), but also of memory and attention. In the early stages, many studies were undertaken with neurological patients. For instance, studies of selective deficits in patients resulted in disclosing the basic anatomy and functional organization of mathematical cognition.[3] A huge breakthrough in this research became possible by the rapid development of neuroimaging methods, such as MRI (Magnetic Resonance Imaging). The progress made has then led to the third phase in the emergence of educational neuroscience. This relatively new field of research intends ‘to use neuroscience to inform educational practice as a way to improve learning’ (Ref. 2, p. 5).

One illustration of the potential of neuroscience for education relates to developmental dyscalculia (DD), a mathematics learning disability characterized by specific and persistent weak achievement in mathematics, notwithstanding otherwise normal levels of intelligence and scholastic performance.[4] The occurrence of the disorder is estimated at 3% to 6% (roughly 1 child in every class). DD is currently considered as a core deficit in representing and processing numerosities. Examples of indicators of dyscalculia are impaired capacity in estimating small sets of objects, and in comparing the quantities of two arrays of dots or two playing cards (e.g. when asked which is the largest of two playing cards, 5 and 8, counting all the symbols on each card). Studies using non-invasive imaging methods have discovered the neural substrates of this disorder, namely structural and functional deficiencies in the brain network that serve numerical and mathematical processing. More specifically, MRI data have revealed differences in this respect between DD and normal developing children in the intraparietal sulcus located in the posterior parietal cortex.[5] From an educational perspective these findings have been useful for the development of diagnostic instruments for the early identification of children at risk of DD, and also for the development of methods for fostering in learners numerical processing, for instance games with manipulables (such as Cuisenaire rods, playing cards) to give children concrete experience of the meaning of numbers.[6]

Such interventions to prevent or remedy low numeracy in children is important not only from an individual point of view but also from societal perspective. Indeed, a study from the OECD shows that an increase of 'one-half standard deviation in mathematics and science performance at the individual level implies, by historical experience, an increase in annual growth rates of GDP per capita of 0.87%.'[7]

A second example of a contribution from neuroscience relates to children's use of strategies for solving simple arithmetic problems, such as $9 + 5 = ?$; $12 - 7 = ?$. We know from research that young children use slow counting strategies based on procedural knowledge for solving such tasks. In contrast, older children and adults rely mostly on faster and more advanced strategies consisting of retrieving the solution from declarative memory. Cognitive neuroscience investigations have recently disclosed the neural substrates of these arithmetic strategies, showing that the two strategies lean on two different areas of the parietal cortex: the procedural strategies on the intraparietal sulcus, but the retrieval strategies on the angular gyrus (e.g. Ansari).[8] Interestingly, this neural difference between the strategies has been shown to converge with the outcomes of self-reporting of strategies, whereby children are asked to report after solving a problem which strategy they have used. In other words, this demonstrates how neuroscience data can provide empirical validation for self-report data whose validity is often questioned.

These illustrative studies show the potential of neuroscience research to contribute to our better understanding of the processes of mathematics learning, and as such to the enrichment of the knowledge base acquired through educational and psychological inquiry.

Notwithstanding this productive dialogue between education, psychology and neuroscience, there is at the same time discussion and conflict concerning the applications of neuroscience to education. Bruer's warning in 1997 that such direct applications are a 'bridge too far' still holds largely true.[9] One reason has to do with the constraints of the neuroscience methods such as neuroimaging in view of guaranteeing sufficient ecological validity to warrant generalization of the results of laboratory studies to learning in the classroom. Furthermore, in those experiments mathematics learning is examined in isolation from the educational environment. Therefore, a major challenge for continues research is to understand how features of the educational context can have an impact on the neural measures obtained through neuroimaging. Finally, as argued by De Smedt and Grabner, 'neuroscience data can deepen our understanding of the cognitive constraints in the learner and the learning process, but they do not directly determine how instruction should be designed to optimally foster learning' (Ref. 4, p. 626).

In conclusion, more interdisciplinary research and dialogue is needed between neuroscience and educational science in view of making progress toward classroom applications of neuroscience. But taking into account the available results of educational neuroscience can, in combination with the knowledge acquired by the learning sciences, already now contribute to better grounded decision-making in designing learning environments.

Mathematics Education: A Crossroad of Many Disciplines

In designing curricula for the different subject-matter domains of school education, one has to combine and integrate content knowledge of the domain (math, science, language, history, etc.) with pedagogical knowledge in such a way that it provides a good basis and starting-point for classroom teaching and learning. Thus, for mathematics education, curriculum development constitutes a crossroad of the content of mathematics, the domain-specific and general pedagogical knowledge, and the knowledge about learning.

About a century ago, the well-known American psychologist Thorndike published a book entitled, *The Psychology of Arithmetic*, wherein he applied his connectionist theory of learning to the teaching of arithmetic, emphasizing the drill and practice of computation procedures.[10] There was, in this case, no dialogue at all with mathematicians and math educators. Of course, conflict was unavoidable, but nevertheless Thorndike has had substantial impact on math education in the USA. Also later in the past century, math education and psychology have continually been intertwined, but for a large part of that era the approaches from both sides were complementary rather than symbiotic, and there was hardly interaction. On the one hand, psychologists used the content of mathematics for studying and testing theoretical issues about cognition and learning without much interest and attention for teaching. On the other hand, math educators were more focused on the what and how of teaching, and often borrowed and selectively used concepts and techniques from psychology. Conflict was closer than dialogue, and sometimes the mutual attitude was critical. For instance, Freudenthal criticized psychological research for disregarding the specific nature of mathematics as a domain and of mathematics teaching.[11] However,

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especially since the 1970s, an increasingly symbiotic and mutually fertilizing relationship between both groups has emerged, and was facilitated by the growing impact of the cognitive movement in psychology, which aimed at understanding the internal processes and knowledge structures underlying human competence. To do this it was necessary to confront people with sufficiently complex tasks so as to elicit the intended information-processing activities. As a consequence, the tasks and problems used in research became more similar to those involved in the subject-matter domains of school curricula. Of great importance was the creation of interactive forums between math education and psychology researchers, such as the International Group for the Psychology of Mathematics Education (PME) founded in 1976. Over the past 30 years, the domain of mathematics learning and instruction has become a fully-fledged and interdisciplinary field of research and study, aiming at a better understanding of the processes underlying the acquisition and development of mathematical knowledge, skills, beliefs, and attitudes, as well as at the design – based on that better understanding – of powerful mathematics teaching-learning environments. During this period, the field has become more and more interdisciplinary as other disciplines besides psychology have joined in the research domain, such as history, philosophy, sociology, anthropology, and epistemology. In 2001 this even led to putting into question the P in PME. In the end the name PME was maintained, albeit that psychology has lost its dominant position.

An illustration of the productive outcomes of the synergy between mathematics education and psychology concerns the research on mathematics-related beliefs on students' learning and performance. Whereas studies inspired by cognitive psychology initially focused on revealing the underlying information-processing aspects of math learning and performance, in the 1980s scholars became increasingly convinced about the impact of affective factors. Schoenfeld defined beliefs as:

> one's mathematical world view, the perspective with which one approaches mathematics and mathematical tasks. One's beliefs about mathematics can determine how one chooses to approach a problem, which techniques will be used or avoided, how long and how hard one will work on it, and so on.[12]

Interesting in this respect is a study about pupils' images of mathematicians by Picker and Berry.[13] They asked 476 12–13-year-old children in five countries (Finland, Romania, Sweden, the UK, the US) to draw a portrait and give an accompanying description of the typical mathematician. Most children drew white men with glasses, often with a beard, bald head or weird hair, and shirt pockets filled with pens, who were working at a blackboard or a computer. Common themes in the drawings and comments in the five countries were:

- *Mathematics as coercion:* the gist of the drawings of many students was that of powerless little children confronted with a mathematician depicted as authoritarian and threatening.
- *The foolish mathematician:* mathematicians were often portrayed as lacking common sense, fashion sense; this way of depicting a mathematician often referred also to an unfair imbalance in power.

Lampert characterizes the common view about mathematics as follows: mathematics is associated with certainty, and with being able to give the correct answer quickly; doing mathematics corresponds to following rules prescribed by the teacher; knowing math means being able to recall and use the correct rule when asked by the teacher; and an answer to a mathematical question or problem becomes true when it is approved by the authority of the teacher.[14] And she also argues that those beliefs are acquired through years of watching, listening and practicing in the mathematics classroom. It is obvious that the views of the children in the study of Picker and Berry as well as the beliefs about mathematics reported by Lampert are not very beneficial to learning mathematics.

A second example illustrates math education as a crossroad of mathematics, psychology and anthropology, indicated as 'ethnomathematics'.[15] Ethnomathematics refers, amongst other things, to informal mathematical practices embedded in specific out-of-school activities and contexts that may be contrasted with school mathematics. For instance, studies of everyday cognition show that people are remarkably efficient in dealing with quantitative problems encountered in their everyday professional and social activities as compared with the school mathematics context. Convincing evidence comes from a well-known and representative study by Nunes, Schliemann and Carraher wherein young street vendors performed very well on problems occurring in the street vending context, such as the following example:[16]

> Someone buys from a 12-year-old street vendor in Recife, Brazil, 10 coconuts at 35 cruzeiros per piece. The boy figures out quickly and accurately the price in the following way: '3 nuts is 105; 3 more makes 210; . . . I have to add 4. That makes . . . 315 . . . It is 350 cruzeiros.'

When the boy who used this rather cumbersome procedure had to solve traditional textbook problems in school, he did much poorer than while doing his business on the street. In the class he did not use the procedures that he used so fast and readily on the street, but he tried to apply the formal algorithms learned in the school, and which he apparently did not master very well. This study illustrates clearly the gap experienced by this boy between the 'real' world and the 'school' world. It is not surprising that in some studies it was found that students believe that school mathematics has nothing do with the real world. These interesting research results have contributed to the development of so-called 'Realistic Mathematics Education': mathematical knowledge and skills have to be acquired and developed starting from phenomena in the real world.

Educational Technology: A Crossroad of Education, Psychology, Computer Science, ….

The use of technology for education goes back about a century, to when Thomas Edison predicted that the motion picture would revolutionize education, and make books obsolete in schools.[17] The revolution did not occur. The next cutting-edge educational technology, radio, also evoked similar high expectations as is illustrated by the following quote from a 1932 book entitled, *Radio: The Assistant Teacher*, by Benjamin Darrow, the founder of the Ohio School of the Air and tireless promoter of radio in classrooms: 'The central and dominant aim of education by radio is to bring the world to the classroom, to make universally available the services of the finest teacher, the inspiration of the greatest leaders.'[18] However, the radio has also never made it in education, and the same happened to its successors, school television in the 1950s and programmed instruction in the 1960s; big promises but ending in a blind alley. The latest cutting-edge technology, the computer and ICT, emerged in schools in the 1980s, and raised even higher optimism and expectations than its predecessors. But again so far these expectations have only partially materialized.

This brief historical overview raises questions about the reasons for these successive failures. A major answer lies in the lack of good dialogue, and the persevering conflict between two different approaches to learning with technology: the technology-centered versus learner-centered approaches.[19] In the technology-centered approach, the computer is just an add-on to an existing classroom situation without much concern about how the human mind works and how students learn effectively. In contrast, the learner-centered approach focuses on how students learn, and technology is conceived as an aid and support for learning integrated in and adapted to the learning environment. But, in addition, the introduction of the technology was not managed appropriately by a kind of business model. For instance, from the 1980s on, computers were massively installed in schools, but the money was mainly spent on the hardware, whereas good software was often lacking. I argued in the 1980s that to create a chance to be successful only one third of the money should be spent on hardware, one third on the development of high-quality software and one third on teacher training. And this brings me to another reason for the technology failure: the teachers were not well prepared and often not very motivated for using ICT in their lessons.

Even the most recent and sophisticated development in educational technology, MOOCs (Massive Open Online Courses), suffers from the mistakes of the past. Initiated less than ten years ago by top universities in the USA (Stanford, Harvard, MIT) MOOCs have rapidly grown and expanded, especially since the establishment of MOOCs platforms such as Udacity, Coursera, and edX. A rather broadly accepted definition of MOOCs is that they are 'online courses designed for large numbers of participants, that can be accessed by anyone anywhere as long as they have an internet connection, are open to everyone without entry qualifications, and offer a full/complete course experience for free.'[20]

But do MOOCs offer a high-quality complete course experience? In many cases they do not. As was recently claimed by Laurillard, a major problem is that the educational and pedagogical quality of many MOOCs is very weak; they are based on a traditional model of education.[21] Or, as argued by Fleming: 'MOOCs are shockingly austere, relying heavily on lectures, multiple choice exams, and threaded discussions with little sustained faculty involvement or guidance for learning.'[22]

However, recently, MOOCs developers and the e-learning community in general have become increasingly aware of the weaknesses of past applications of technology for education.[23] It is obvious that future more successful and high-quality use of technology for education requires dialogue and collaboration between a variety of disciplines, each of them with an emphasis on their specific expertise.

- Education/pedagogy: establishing concerted action with all stakeholders in defining objectives, and developing assessment instruments.
- Psychology of learning: providing models of active and effective learning.
- Learning design science: formulating design principles for the development of (virtual) learning environments taking into account models of effective learning.
- Discipline experts: responsible for the content knowledge of the disciplines of the curriculum (math, physics, chemistry, geography, etc.).
- Curriculum development: responsible for the appropriate integration and embedding of technological tools in the curriculum.
- Computer science and ICT, hardware as well as software specialists, taking care respectively of providing the appropriate equipment, and the development of the software needed to support effective student learning.
- Economics: taking care of operational, organizational and financial aspect of the implementation of technological tools; developing business models for the design and use of MOOCs.
- Anthropology: taking into account ethnic and socio-cultural differences for programs, courses (e.g. MOOCs) designed for use with different subgroups of the population and in distinct regions of the world.

Final Comments

In the preceding sections I have argued and illustrated the need for dialogue and collaboration with other disciplines in educational research and development, focusing on the micro-level of the educational system. However, such interdisciplinary collaboration is also necessary with respect to issues and problems at the intermediate and macro-levels. For instance, studies focusing on the analysis and innovation of education at the school level require disclosing the pedagogical views of school leaders; but also the contribution of psychology in profiling school leaders, in analyzing the social and working relations and interactions amongst the staff; the input of sociology for mapping out the demographic and socio-cultural context of schools, in particular the relationship with the parents; the contribution of economics and business administration in portraying the financial situation and management structure of the institutions and in developing a strategy for innovation. If innovation of the infrastructure is also involved, collaboration with architecture and interior design is also necessary.

The complexity of educational phenomena from which the need for dialogue and collaboration between disciplines derives, together with the reality that contexts and variables that impact education are often uncontrollable, has brought Berliner to claim that educational research is the hardest science of all: 'Doing science and implementing scientific findings are so difficult in education because humans in schools are embedded in complex and changing networks of social interaction.'[24]

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