

International Bureau of Education

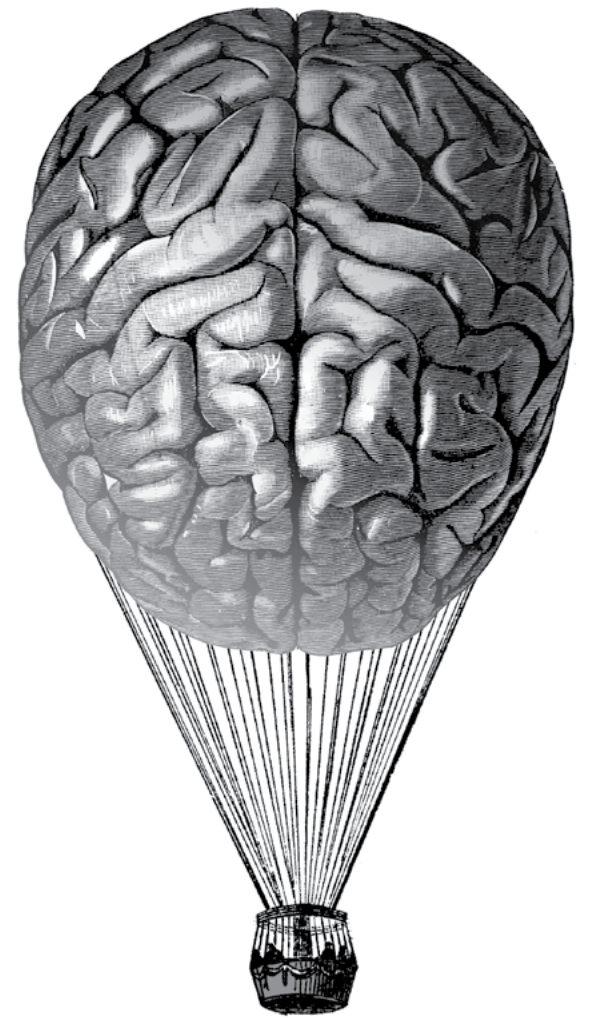
IBE

INFOCUS



EDUCATION & THE FUTURE

AT THE INTERFACE OF NEUROSCIENCE
AND TECHNOLOGY



ingenuity



Message from the Director

Mmantsetsa Marope
Director, IBE-UNESCO

For this issue of *IBE In Focus*, the focus is on the interface of technology, neuroscience, and learning. A bit of an abstract cross-point, but nonetheless, one that is indispensable for the future of education and learning.

This issue adds the IBE’s voice to the raging global debate on the future of education and learning. At the heart of this debate is the urgent need to provide all global citizens with quality, development-relevant education that prepares them for fast-changing twenty-first century work and life contexts. The current global learning crisis remains a formidable hurdle, and a clear threat to the attainment of individual, collective, national, and global development goals through education and learning. The global education community must address this crisis with renewed determination and decisiveness. Without such resolve, the world will forfeit SDG 4 and the other 16 SDGs, the attainment of which depends on high thresholds of well-prepared human resources.

In the global effort to push back on the crisis, credible neuroscientific knowledge of human learning, and emerging technologies remain under-explored levers. To accelerate the dialogue, this issue first takes the reader through what emerging technologies are and why they matter in the future of education and learning. A call is made for the optimal use of emerging technologies for public good and for measures to mitigate their potential risks. This issue also walks the reader through advances in the science of learning (SoL), especially neuroscience, and discusses why these matter to the future of education and learning. The vital role of emerging technologies, especially neuroimaging technologies, in advancing neuroscientific understanding of the learning brain is made evident. The issue calls for better leveraging of emerging technologies and neuroscience to attain and sustain quality and development-relevant education and learning for all.

However, access to credible neuroscientific knowledge and to technology is inequitable within and across countries. Unsurprisingly, this issue of *IBE In Focus* echoes the voices of heads of state in calling for equitable access to both resources, lest we risk exacerbating current inequalities.

Thanks to exceptional contributions from global thought leaders in the three fields of focus—technology, neuroscience, and learning—this edition is rich in content and truly thought provoking. It is enriched further by interviews with eminent personalities, including the humanoid robot, Sophia: the Saudi Lady, the Ambassador for AI Tutor, and the UNDP Champion for Innovation.

Still more thanks are due for the grace and guidance of current and former heads of state who weigh in on key messages of this issue. I am honored and humbled by their wisdom, guidance, and generous support.

I cannot thank enough the partners who carry *IBE in Focus* to its esteemed readers, including: The VIP lounges of the Monaco Yacht Club, the Montreux Jazz Festival, La Réserve Hotel, in Geneva; the first- and business-class lounges of Swiss Air and South African Airways; and the Protocol Lounge at Geneva Airport. I am also grateful to the IBE’s commercial partners, whose advertisements contribute to the production of this magazine.

Sincere gratitude to the valued readers and followers of *IBE In Focus*. Enjoy this issue, and please keep sending us your insightful comments and suggestions. They go a long way towards improving this magazine, as it grows from strength to strength, into a flagship publication of the IBE.

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Statement from the President
of the IBE Council



Marat Kozhakhmetov
President, IBE Council

The IBE’s activities in 2018/2019 were marked by great achievement, even by the standards of an organization in which exceptional performance is the rule.

During 2018/2019, the IBE consolidated its global intellectual leadership and standard-setting functions in curriculum, teaching, learning, and assessment. It did so by establishing sustained impact through a broad portfolio of global projects, by reinforcing its convening power, by building strong networks and communities of practice, and by developing a solid internal knowledge base. The IBE has fulfilled its core functions while remaining true to its long-term mission: to strengthen the capacities of Member States to design, develop, and implement curricula that ensure the equity, quality, development-relevance, and resource-efficiency of education and learning systems.

We live in a century where, in IBE Director Marope’s words, “change is the only constant”. In a context of rapid social, political, economic, and technological change, learning is a critical source of the adaptability, agility, and resilience required to meet new challenges and opportunities. How can education and learning respond effectively and far-sightedly to the challenges of an uncertain future?

The IBE continues to create agile and lasting initiatives that

respond to the ever-changing environments of education and learning. The ability of education and learning systems to prepare learners for their future work and lives—the directions of which remain unknown—is a recurrent theme of the IBE’s discourse and activities. The IBE’s more recent projects have been inspired by five normative papers developed by the IBE Director and her colleagues on the future of curriculum. Some of the IBE’s related thinking, projects, and partnerships are highlighted in this splendid publication, which focuses, fittingly, on neuroscience and emerging technologies for the future of education and learning.

Developed since 2015, when few educationists embraced futuristic thinking, these normative documents are distinguished by their intelligence, insight, and audacity. They discuss a future paradigm shift in relation to curriculum, consider the transformation of teaching, learning, and assessment, propose a global future competence framework, ask what constitutes a quality curriculum, and present a prototype national curriculum framework. They serve as global reference points for Member States seeking to develop curricula that can prepare learners for the future of work and life in fast-changing contexts.

These documents, when applied to real-life contexts, highlight the

IBE’s unique position to act as a global platform for innovative interaction and evidence-based policy.

I would like to thank the IBE partners, UNESCO Member States, and the IBE Council members, for their profound and unwavering commitment to the IBE and their vital participation in its activities. Now, more than ever, we need to support and strengthen the IBE, so it can continue to serve Member States in its key mission to transform education and learning systems for the better.



Over 100 destinations.

But really just one way to get there.



FORWARD LOOKING BACK TO MOVE «»



FROM
IDEAS AND NORMS
TO IMPLEMENTABLE
CURRICULA

by

Mmantsetsa Marope



Like the mystical
Sankofa of
Asante Adinkra
symbology,
the IBE looked
back on 2017
in order to move
forward
in 2018/2019.

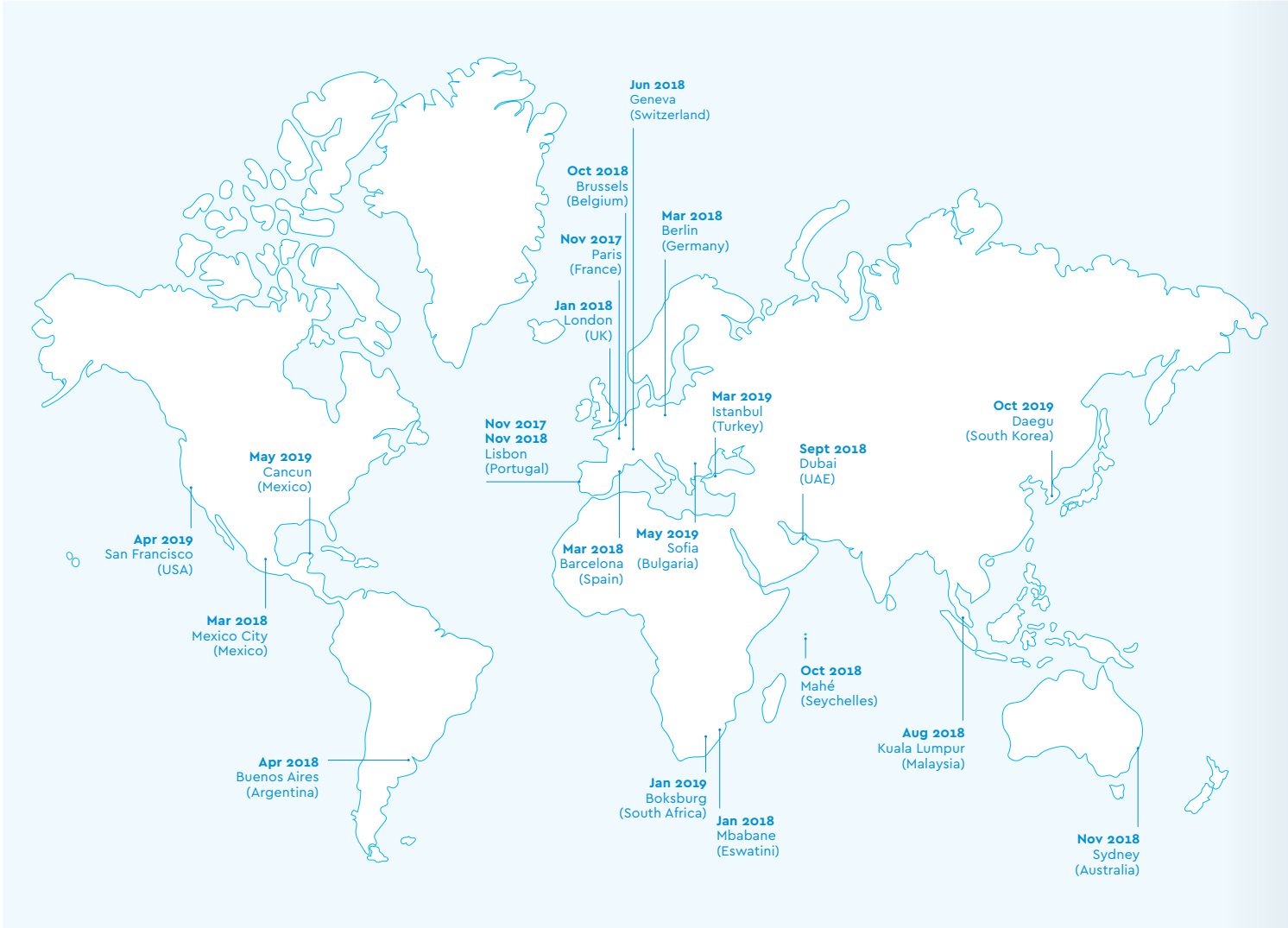


2017 was the year to consolidate the IBE’s global intellectual leadership and its norms- and standard-setting functions in curriculum, teaching, learning, and assessment. Through a consultative process, the IBE prepared normative documents to serve as global reference points for countries seeking to develop curricula that can prepare learners for the future of work and life in fast-changing contexts. These documents encompassed the following: a future paradigm shift on curriculum; the transformation of teaching, learning, and assessment required to best support future curricula; a global future competence framework; a study of what constitutes a quality curriculum; and a prototype national curriculum framework. In order to clean up and streamline the language of intellectual and conceptual dialogue on curriculum, the IBE also expanded and updated its *Glossary of Curriculum Terms* in line with its futuristic thinking on the field. Collectively, these intellectual and normative products form part of the IBE’s growing compendium meant to guide the future of K-12 curriculum.

By the end of 2017, the IBE shared its normative work on the future of curriculum with ministers of education and their senior experts during a side event of the 39th session of the UNESCO General Conference. Ministers applauded the work, calling strongly on the IBE to ensure its wide dissemination and to provide



The IBE Science of Learning Portal features technical briefs on relevant neuroscience topics, with clear implications for education policy, teaching, and learning.



concrete examples of its implementation in real contexts of their curricular reforms. This ministerial call set the stage for most of 2018/2019.

Disseminating

normative and other intellectual products

By the middle of 2019, these five normative documents on the future of curriculum had cumulatively been downloaded 4,815 times from the IBE website. On demand from Member States and their institutions, they were presented in prestigious forums across 20 cities, multiple times and to different audiences.

The IBE *Glossary of Curriculum Terms* enjoys wide recognition and usage, as evidenced in its extensive citation in the *OECD Curriculum Glossary* and its adoption by UNICEF for use in the Arab States, including its translation into Arabic.

Translating

norms into future-relevant curricula

Adopting a norm does not guarantee capacity for its implementation. Consequently, translating norms

into impactful curricula is often a long and less travelled road. Not surprisingly, in 2017 ministers of education asked the IBE to provide concrete examples of the application of its normative work in real contexts of curricular reforms. Seven countries and 26 institutions benefitted from the IBE’s technical support in translating normative work into implementable programs. Afghanistan, Eswatini, Kenya, Myanmar, and Seychelles received technical support to align their national K-12 curricula with the IBE’s paradigm and future competence framework. South Africa engaged the IBE in technical dialogue, on the basis of which it adopted its global future competence framework and proceeded to use its own technical capacity to apply the framework in improving its K-12 curriculum. Kuwait engaged the IBE’s services to undertake a technical audit of its K-12 competence-based curriculum to ensure its alignment with the IBE’s futures perspective on curriculum and with global best practices. The International School of Geneva (ECOLINT) in Switzerland and a chain of 25 Mektebim schools in Turkey also adopted the IBE’s global future competence framework. For ECOLINT, the IBE framework guided the whole curriculum with a view to transform the school into an IBE Flagship School. For Mekte-

Above:
IBE’s normative documents were presented in prestigious global forums.

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AT A GLANCE

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7

countries received technical support to translate the IBE’s normative work into implementable programs.

4

countries received technical support to align their national K-12 curricula with the IBE’s paradigm and future competence framework.

23

countries converged in Seychelles to share best practices in ECCE.

4

countries began to integrate STEM education into their policies and curricula.

7

countries started to re-orient their curricula towards a competence-based approach.

26

schools adopted the IBE’s global future competence framework.

18

countries gained a deeper understanding of the global framework through a consultative forum for its validation.

4

countries received technical support for the implementation of GCED policies and programs through their curricula.

13

countries have IBE graduates in leadership positions.

5

countries joined peer learning sessions in preparation for revising their ECCE curricula.

bim schools, support was provided to transform their STEM curriculum into a competence-based STEM Best Practice Futures Curriculum.

Strengthening

technical capacity to implement norms and standards

Sustained compliance with global norms and standards requires technical leadership capacity at a national level. During 2018/2019, the IBE sustained capacity development through the skills transfer embedded in technical assistance, direct training, provision of resource materials, peer learning, and dissemination of promising practices and innovations. Cambodia, Mongolia, Colombia, and Uganda received technical support for the implementation of global citizenship education (GCED) policies and programs through their curricula. An IBE conceptual framework was applied to analyze secondary-level youth education in Argentina, Brazil, Chile, Mexico, and Peru. In addition, 18 countries gained a deeper understanding of the framework through a consultative forum for its validation.

A range of IBE resource materials buttressed technical and operational capacities of curriculum practitioners across Member States, including a Guide for Developing and Implementing Teacher Education Curriculum Frameworks, aligned with the IBE future-competence framework. Its dissemination was enhanced through translation into Arabic, French, and Spanish. The *Resource Pack for Gender-Responsive STEM Education* was translated into French, raising the possibility of its application across Francophone countries. In collaboration with the Organization of Ibero-American States, the *Guide for Enhancing Inclusion and Equity in Education* was made available online in English, Portuguese, and Spanish with a view to benefitting 22 partner countries. The English version of the IBE GCED Resource Pack was placed online, to support Member States’ mainstreaming of GCED in their curricula. The Curriculum Resource Pack was updated and—already in English and Spanish—translated into Arabic and French. *Reaching Out to All Learners: A Resources Pack for Supporting Inclusive Education* was also translated into Arabic and made available online.

IBE-accredited certificate, postgraduate, and master’s programs run with partner universities continued to raise the threshold of technical leadership for curricula at the country level. The regional Master’s in Curriculum and Learning course for the Arab region was developed and is now being implemented. Existing master’s courses for Africa and for Latin America and the Caribbean were upgraded to take into account recent IBE knowledge outputs. The IBE ran a course on leading curriculum reforms, tailored for senior curriculum experts in Malaysia. It ran another tailored course—on effective implementation of competence-based STEM curricula—for around 100 teachers in Mektebim schools in Turkey. Combined,



these courses have now benefitted participants from 80 countries.

The technical and operational capacities of Member States were further strengthened through peer learning and exchange of best practices. For early childhood education and development (ECCD), in particular, the IBE co-convenes (with Seychelles) a biennial international conference that brings together countries at different levels of advancement in the field. In February 2019, participants from 23 countries met in Seychelles for this purpose. This biennial platform also promotes south-south, north-south, and south-north collaboration across Member States. So far, collaboration has focused both on addressing institutional fragmentation—which undermines the delivery of holistic EC-CD services to children under 8 years of age—and on building reliable data systems to monitor holistic early childhood development and to push forward with SDG 4.2. Earlier in 2018, high-level experts from all over the

Careful development of quality and future-relevant curriculum is an indispensable starting point in preparing learners for the future of work and life.

Above:
IBE Director, Mmantsetsa Marope, in dialogue with Pierre Magistretti, Brian Butterworth, and Stanislas Dehaene. High-level Forum on Neuroscience and the Future of Education and Learning, Daegu, 23 September 2019.

TECHNICAL PARTNERSHIPS

With prestigious research centers on the science of learning

MID-2019

★

Institute for Learning & Brain Sciences, University of Washington

★

Queensland Brain Institute, University of Queensland

★

Technology-enhanced Learning in Science, University of California, Berkeley

★

Laboratoire de Psychologie du Développement et de l'Education de l'enfant, Université de Paris Descartes

world met in the United Arab Emirates to share their experiences of building resilient ECCD systems and in monitoring holistic early childhood development.

The IBE continued to bolster peer learning by disseminating information about promising practices and innovations from Member States through its *bi-weekly Alerts* and *Digests*. In 2018/2019, it disseminated online a total of 40 Alerts and 7 Digests. Alerts subscribers increased by 72%, from 794 in 2017 to 1,371 by mid-2019. The IBE also launched a quarterly newsletter that mainly targets members of the IBE-UNESCO Global Curriculum Network (GCN) and provides a platform for sharing promising and innovative practices from their respective countries. During 2018/2019, the GCN supported active members from 138 countries, expanding to faculties of education with robust curriculum programs across 142 universities in 39 countries.

Translating

neuroscience research to inform teaching and learning processes

Careful development of quality and future-relevant curriculum is an indispensable starting point for preparing learners for the future of work and life. However, without effective teaching, impressive curricula represent ineffectual documents and unrealized potential. The persisting global learning crisis suggests that effective teaching still eludes an uncomfortably large number of education systems, including those with impressive curriculum documents. As 2030, the target date for the Sustainable Development Goals, draws closer, it is a pressing imperative that the global education community renew efforts to improve effectiveness at facilitating learning. At least in part, this calls for the strengthening of teachers' scientific understanding of the learning brain.

Proceeding from a premise that a better understanding of human learning should enrich teachers' insights on effective teaching, the IBE redoubled its efforts to translate findings from credible neuroscience research to informing teaching and learning. This translation work is in the form of short and accessible technical briefs that make evident the implications of research findings for teaching and learning. During 2018/2019, the IBE added a new set of 36 briefs to the 30 already completed in 2017.

The IBE's capacity to expand this work should grow quickly, thanks to its technical partnerships with prestigious research centers on the sciences of learning at the universities of Member States. By mid-2019, the IBE had established such partnerships with the Institute for Learning & Brain Sciences, University of Washington; the Queensland Brain Institute, University of Queensland; Technology-enhanced Learning in Science, University of California, Berkeley; Western University, Canada; and Université de Paris Descartes. More partnerships are soon to be signed with Beijing Normal University; the Cuban Neuroscience

Center; Universidad de la República, Uruguay; and University of Cambridge.

The IBE developed its Science of Learning Portal during 2018/2019 to expand access to technical briefs to teachers (first and foremost), other education practitioners, researchers, and policymakers. The IBE also began integrating neuroscience into its current training programs for curriculum specialists. In addition, it began developing curricula modules on neuroscience for Member States to include in their teacher pre- and in-service training programs. As the IBE develops course materials, Seychelles has volunteered to pilot them and to improve their impact, while gaining a head start.

To anchor this work in national policies and practices, the IBE co-convened with the International Brain Research Organization (IBRO) a ministerial dialogue on neuroscience and the future of education and learning during the 10th World Congress on Neuroscience, in September 2019. The dialogue specifically targeted ministers from Africa, Arab states, South Asia, and West Asia, where neuroscience is yet to be mainstreamed into pre- and in-service programs for educators—especially, though not exclusively, teachers.

Building

capacity for effective learning
from the base

Effective teaching is essential for facilitating learning. However, it needs to be underscored that, ultimately, it is the learners who do the learning, not the teachers. The latter can only facilitate the former. The most effective teaching in the world will not realize commensurate learning outcomes if it is not complemented by an effective capacity to learn. For many children, a range of factors—including malnutrition, diseases, fatigue, toxic stress, non-conducive home environment—undermine their capacity to learn. Yet, effective learning is just as important to effective curriculum implementation as effective teaching, if not more so. Thus, while it is important to support teachers in effective teaching, it is even more important to support learners in effective learning.

Compelling research evidence speaks to the indispensable role of quality and holistic ECCD services in building capacity for effective lifelong learning. Yet, to date, a little under half of the world’s children do not have access to such programs. Where programs exist, their quality and effectiveness remain unclear, especially for ages 0-3, the most critical age for building effective learning capacity. More often than not, delivery of ECCD services to children aged 0-8 years old is undermined by institutional fragmentation and by poor capacity to monitor holistic early childhood development.

During 2018/2019, the IBE deepened its effort to build capacity for effective learning from the base. It

Right:
IBE Director delivers opening remarks, High-level Forum on Neuroscience and the Future of Education and Learning, Daegu, 23 September 2019.



The IBE/IBRO High-level Forum on Neuroscience and the Future of Education and Learning brought together, for the first time, ministers of education, their senior experts on teaching and learning, and world-class neuroscientists to explore the untapped potential of science to transform education and learning.

advanced work toward articulation of an ECCD System Prototype. Furthermore, it provided Cameroon, Eswatini, Seychelles, Laos, and Rwanda with technical support to apply the evolving prototype toward strengthening their national ECCD systems. The same countries also piloted the evolving Holistic Early Childhood Development Index (HECDI) to improve the monitoring of their systems’ impact on holistic early childhood development.

Reinforcing
the monitoring of SDG 4.1

Assessment collect evidence of effective learning through the proxy of learning outcomes. Curriculum guides teaching, learning, and assessment. Logically, intellectual and technical leadership for monitoring learning outcomes is within the core competences and mandate of the IBE. During 2018/2019, the IBE completed an analysis of the National Assessment Frameworks (NAFs) of 73 countries for reading and of 115 countries for mathematics in order to ensure the development of credible Global Assessment Frameworks (GAFs) for SDG 4.1 (reading and mathematics). Following extensive consultations, these frameworks were adopted for use in monitoring SDG 4.1.

Stimulating
reflective dialogue on areas
of IBE competence

The IBE’s *In Progress Reflections* (IPRs) continued to stimulate reflective dialogue on critical and emerging issues on curriculum, teaching, learning, and assessment. Fifteen IPRs were developed and disseminated during 2018/2019.

Strengthening
internal intellectual and operational capacity

The effectiveness of the IBE at executing its mandate rests on its own internal capacity and on opportunities for its constant renewal through staff learning. Staff efforts are augmented through the IBE Learning Series, which is also open to International Geneva, especially education professionals. During 2018–2019, the IBE staff participated in 5 IBE sessions, titled: *The Future of Africa: AI, Robotics, and Education; Educating for the 21st Century: 7 Global Challenges; Neuroscience and Education: Addressing the Global Learning Crisis; Migration, Displacement and Education: Building Bridges, Not Walls; and Immigrants and Comparative Education: Call to Re/Engagement.*

2018/2019 also witnessed an impressive growth in the base of IBE Senior Fellows, who, by all measures, are an integral part of the institutional brain trust. The IBE Senior Fellows have immense expertise and enviable experience in the following fields: competence-based curriculum, futures curriculum, neuroscience of education and learning, cognitive psychology, reading and writing in the early grades, teaching, teacher ed-

**IBE
LEARNING
SERIES
EVENTS**

2018-2019

1
The Future
of Africa:
AI, Robotics, and
Education

2
Educating
for the 21st
Century: 7 Global
Challenges

3
Neuroscience
and Education:
Addressing the
Global Learning
Crisis

4
Migration,
Displacement
and Education:
Building Bridges,
Not Walls

5
Immigrants
and Comparative
Education:
Call to Re/
Engagement



Above:
Group photo,
High-level Forum on
Neuroscience and the
Future of Education
and Learning,
Daegu, 2019.

ucation and continuous professional development, ECCD, assessment for learning, STEM education and learning, technology education, AI and education, and robotics and AI in the early grades.

An exceptional base of consultants augmented the expertise and experiential base of IBE Senior Fellows. Combined, senior fellows and consultants are what give the IBE the agility for constant self-renewal and flexible constitution of teams whose skill mix measures up to the task.

Adopting a norm does
not guarantee capacity
for its implementation.
Consequently, translating
norms into impactful curricula
is often a long and less
travelled road.

Visibility on world stages

External perception of the IBE's excellence is evident in the level and prestige of the roles it is called on to perform around the world. Within two years of 2018/2019, the IBE staff held prominent roles in global forums, serving as featured speakers, keynote speakers, and as speakers in plenary sessions and/or presidential panels.

Most significantly, the IBE consolidated its global convening power and its recognition as an intellectual partner of choice. For example, it played an important role in the Annual Conference of the Comparative and International Education Society (CIES), the World Congress of Comparative and International Education Societies (WCCES), the International Biennial Conference on Early Childhood Care and Education, and the IBRO World Congress of Neuroscience.

2017
NOVEMBER
— **Featured speaker:** *Future Competences and the Future of Curriculum*. Side event on *Future Competences and the Future of Curriculum*, 39th session of UNESCO General Conference, Paris.
— **Featured speaker:** *Investing in People, Skills, Infrastructure, and Opportunities*, WebSummit, Lisbon.
— **Panelist:** *Learning Inside and Outside the Classroom*, WebSummit, Lisbon.

2018
JANUARY
— **Keynote speaker:** *Competences for the future workplace*, Junio Achievement Worldwide Forum, London.
— **Featured speaker:** *From Global Competence to National Success*, Education Fast-forward Debate, Education World Forum, London.
— **Keynote speaker:** *Policy for Curriculum and Competences in the 4th Industrial Revolution*, Education World Forum, London.

FEBRUARY
— **Keynote speaker:** Plenary on *Universal Learning Program*, Pedagogical Day, International School of Geneva, Switzerland.
— **Keynote speaker:** IBE mission, Mbabane, Eswatini.

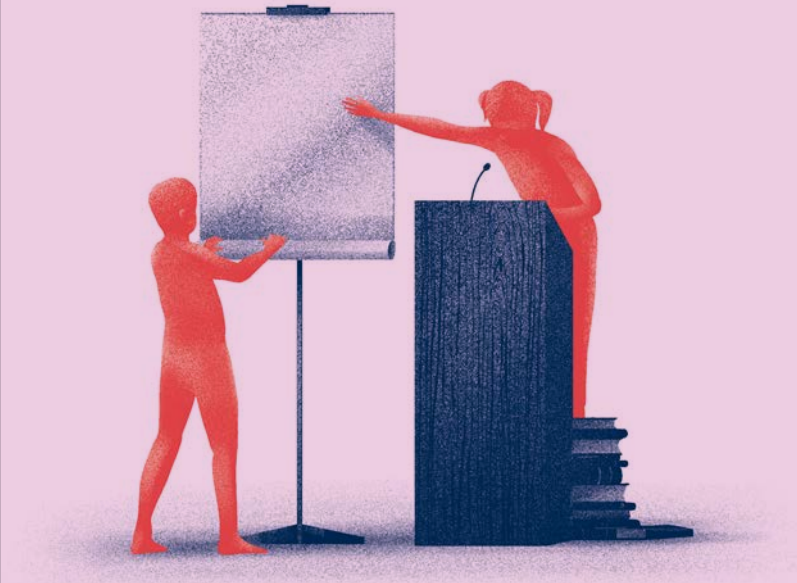
MARCH
— **Keynote speaker:** *Future competences for sustainable development: A smart investment*, Berlin Economic Forum, Berlin.
— **Keynote speaker:** *The future of curriculum: Transforming teaching, learning, and assessment*, UNESCO Catalonia Conference, Barcelona.
— **Speaker and Chair:** *Learning, education, and the unknown tomorrow: Competences for the 21st century*, Presidential Highlighted Panel, CIES Annual Conference, Mexico City.

APRIL
— **Plenary speaker:** *Global competences and the future of curriculum*, G20 Education Working Group, Buenos Aires.

AUGUST
— **Speaker:** Training MoE, Kuala Lumpur, Malaysia.

SEPTEMBER
— **Co-convenor:** High-level consultative meeting on ECCE, Dubai.

OCTOBER
— **Speaker:** Technical assistance to MoE and Institute for Early Childhood Development (IECD), Victoria, Seychelles.
— **Featured speaker:** Sustainability Salon, Brussels.



NOVEMBER
— **Featured speaker:** *Emerging technologies: Building the workforce of the future*, WebSummit, Lisbon.

2019
JANUARY
— **Keynote speaker:** *Preparing learners for fast-changing future*, South Africa Basic Education Lekgotla, Boksburg.

FEBRUARY
— **Keynote speaker and Co-convenor:** 2nd International Biennial Conference and Early Childhood Care and Education on *Big Data for Small Children: Monitoring Holistic Early Childhood Development*, Victoria, Seychelles.

MARCH
— **Featured speaker and Co-convenor:** *Competence-based STEM curriculum*, International STEM Education Summit, Istanbul.

APRIL
— **Plenary speaker:** *Reconceptualizing and repositioning curriculum in the 21st century: A global paradigm shift*, Presidential Panel, CIES Annual Conference, San Francisco.
— **Co-sponsor and Partner,** CIES Annual Conference, San Francisco.

MAY
— **Plenary speaker:** *The future of education and work*, Webit. Festival Europe, Sofia, Bulgaria.
— **Keynote speaker:** *Shaping the future of education or shaping the future through education*, 17th WCCES Congress, Cancun.
— **Co-convenor and Co-sponsor:** WCCES Congress.

SEPTEMBER
— **Featured speaker:** 10th IBRO World Congress of Neuroscience, Daegu, South Korea.
— **Co-convenor and Co-sponsor:** High-level Forum on *Neuroscience and the Future of Education and Learning*, Daegu, South Korea.
— **Keynote speaker:** *Global Gender Equality Imperative in STEM Education*, High-level Dialogue on *STEM Education and the Global Equity Imperative*, Daegu, South Korea.

DECEMBER
— **Convenor and Sponsor:** Forum on *Establishing Resilient National ECCE Systems*, Reggio Emilia, Italy.

Digitization of historical textbook collection and historical archives

The IBE holds a rare historical collection of textbooks dating back to 1700 in over 100 languages. Efforts to conserve and expand access to this collective heritage of UNESCO Member States were sustained. By mid-2019, following rigorous quality-control checks, the IBE had digitized and quality-assured 4,600 historical textbooks and over 500 photographs, including the entire historical archives—1925 to 1969—and every page (nearly 2 million) of each digital surrogate. In total, the IBE catalogued 7,344 textbooks and archival dossiers and secured them in a digital library, according to international standards; 1,322,943 files were in digital form.

The IBE curated its historical textbook collection and historical archives, displaying them in the IBE Documentation Center and across 7 exhibitions held within prominent forums such as the World Congress of Comparative Education Societies (WC-CES) and the Comparative and International Education Society (CIES) Annual Conference.

Publications and resources

Knowledge creation, management, and brokerage are integral to the role of IBE as a global center of excellence. Diverse knowledge outputs of 2018/2019 evidence this role.

IBE Book Series
— Education for the 21st century: Seven global challenges.
— Improving early literacy outcomes: Curriculum, teaching, and assessment.

Prospects
— Literacy and the Sustainable Development Goals: From agenda to action.
— Dilemmas and hopes for human rights education.
— Preventing violent extremism through education: From policy to practice.

Educational Practices
— Accountable talk: Instructional dialogue that builds the mind.
— Proportional reasoning.



VISIBILITY ON WORLD STAGES

Expanding access to IBE's knowledge products

The IBE continued to broaden access to its knowledge products using a variety of channels.

The circulation of IBE's flagship journal, *Prospects: Comparative Journal of Curriculum, Learning, and Assessment*, has been enhanced greatly by its translation into Arabic and Mandarin Chinese, as well as by the quality of its content. For instance, one of its articles, "Stumbling at the first step: Efficiency implications of poor performance in the foundational first five years", was nominated by Springer as one of the top 100 influential education articles of 2018.

Visits to the IBE's website, which carries most of IBE knowledge outputs, grew from 734,062 in 2017, to 1,013,301 by the end of 2019. This is projected to grow even more with the expected launch of the new website in 2020. As noted, the dedicated IBE Science of Learning Portal is anticipated to further enhance the dissemination of credible neuroscientific knowledge.

The IBE flagship magazine, *IBE in Focus*, which carries knowledge products in popular language, also increased in circulation. 2000 physical copies of the magazine were distributed in 2018–2019, mostly at prestigious global forums.

Its downloads increased from 495 in 2018 to 1,389 by the end of 2019.

Vignettes of IBE knowledge products and activities were disseminated through Twitter, whose following increased from 3,250 in 2017, to 5,973 in 2019. The IBE Director's Twitter following also increased—from 4,103 in December 2018 to 5,419 in December 2019.

Strategic partnerships are the key to the IBE's success. The past year saw clear growth in prestigious intellectual partners, consistent with the IBE's role as a center of excellence and as an intellectual leader in its areas of competence. It also added several partners that are critical for ensuring the credibility and global ownership of the IBE's normative instruments. Of particular importance has been the growth in the membership of the GCN and the convening of global thought leaders on the future of curriculum. The IBE has also started to establish Best Practice Hubs based around partner countries that excel in the IBE's flagship programs. Short-term collaborators have also increased within UNESCO structures and across sister organizations.

Partnerships

Best Practice Hubs

- The Republic of Seychelles [ECCE].

Sciences of Learning Centers

- Queensland Brain Institute, University of Queensland, Brisbane, Australia.
- Institute for Learning & Brain Sciences, University of Washington, US.
- Technology-enhanced Learning in Science, University of California, Berkeley, US.
- Laboratoire de Psychologie du Développement et de l'Education de l'enfant, Université de Paris Descartes, France.
- Brain and Mind Institute, Western University, Canada.

More partnerships are soon to be signed with:

- Center for Educational Neuroscience, Beijing Normal University, China.
- Centro Cubano de Neurociencias (CNEURO), Cuba.

Academic and Professional Organizations

- International Brain Research Organization (IBRO).
- Institute for Cultural Diplomacy, Germany.
- Comparative and International Education Society (CIES), US.
- World Council of Comparative Education Societies (WCCES).
- Institute for Early Childhood Development, Seychelles.

Global Curriculum Network (GCN)

- 138 countries.
- Faculties of Education with strong curriculum programs across 142 universities in 39 countries.

Partner Universities for IBE-Accredited Training Programs

- Dar es Salaam University, Tanzania.
- Kaunas University of Technology, Lithuania.
- Hamdan Bin Mohammed Smart University, UAE.
- Catholic University of Uruguay, Uruguay.

Partners and distributors of IBE In Focus

Private sector, foundations, trusts, and philanthropists

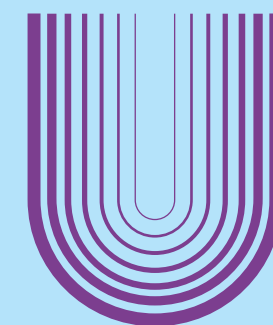
- Dubai Cares, UAE.
- Green Leaves Foundation, Switzerland.
- Anonymous foundation, Switzerland.
- International School of Geneva, Switzerland.
- Mektebim schools, Turkey.

UNESCO Member States that provide voluntary contributions

- The Republic of Seychelles.

- South African Airways
- Swiss Airlines
- La Réserve Hotel, Geneva
- Montreux Jazz Festival
- Monaco Yacht Club
- Espace Kofi Annan, Protocol Lounge, Geneva Airport.





UNPACKING

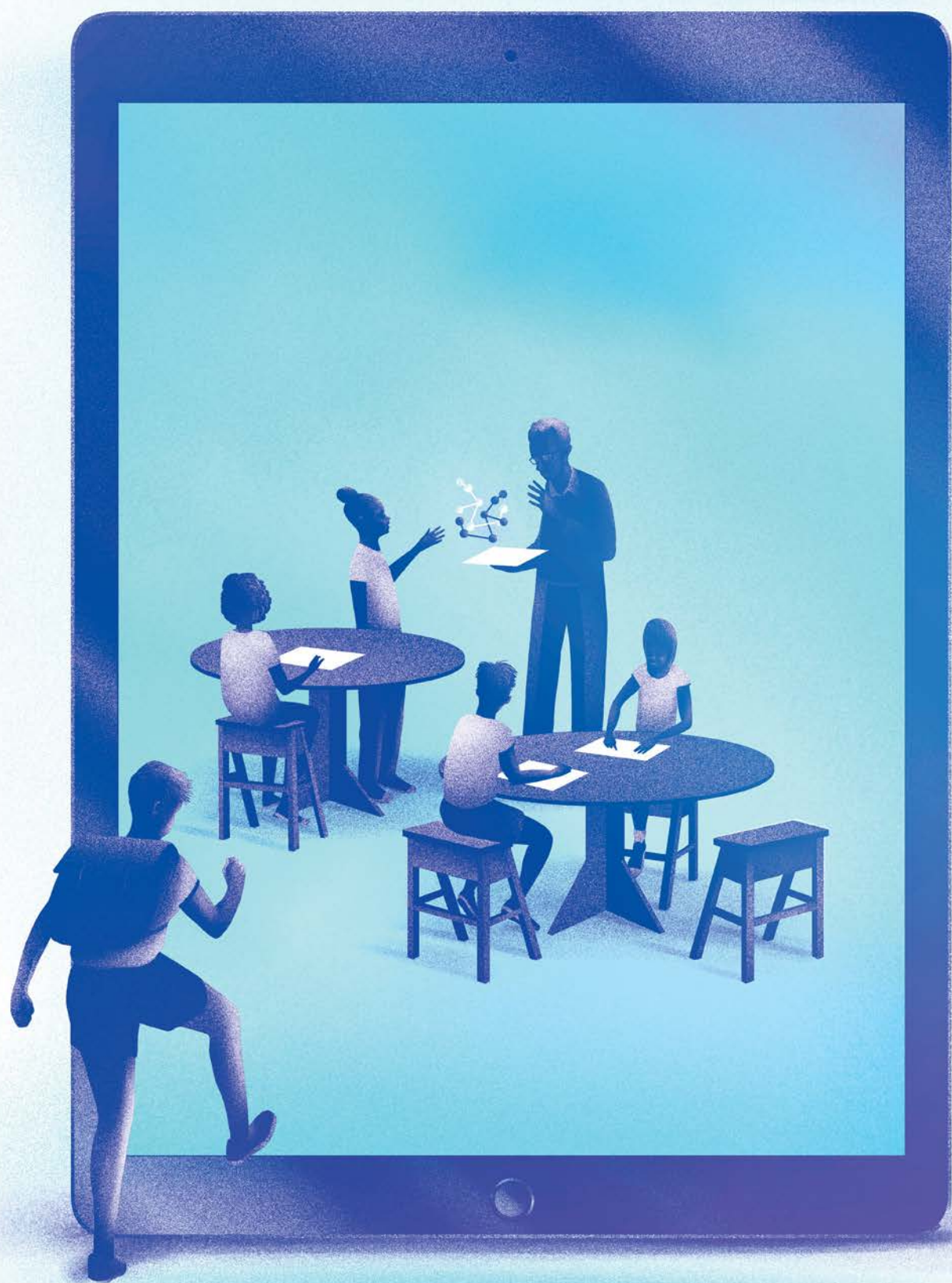
EMERGING TECHNOLOGIES

What are emerging technologies and why do they matter for the future of education and learning? How can education and learning systems make optimal use of emerging technologies for public good, and to build the technical, innovative, and anticipatory capacities required for constant self-review and self-renewal? If these questions interest you, read on.



Historic education gains have been made over the past 25 years, but significant deficits remain. The global learning crisis is holding many countries back. We cannot narrow the skills gap as long as hundreds of millions of children reach young adulthood without having learned the basics. We can and must all do more to ensure that quality education becomes a reality for all. As a global community, we need to galvanize efforts so that in 10 years—our 2030 deadline—we can look back and see that we kept our promise to leave no child behind.

Hon. Julia Gillard
Chair, Global Partnership for Education
Former Prime Minister of Australia



LEVERAGING
EMERGING

TECH

FOR
EFFECTIVE
TEACHING
AND
LEARNING

by

Cynthia Borja, Mishel Tirira,
Tracey Tokuhamu-Espinosa



Emerging technologies have huge potential to improve teaching and learning, and to create networked communities of learners around the world.



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New technologies are full of promise. They are constantly evolving and adapting to an ever-changing world and to users' needs. Technological tools can be found for nearly every aspect of life. Chances are that if you can imagine a practical need in your life, a tool exists to facilitate it, including in education. A simple search on a phone results in thousands of options that a teacher can use to facilitate classroom learning. Rather than being at a loss for resources, educators, students, and teachers are challenged by choice.

To better understand the variety of educational tools available to teachers, it is helpful to divide them into different levels. At a macro level, technologies related to instructional design elements, such as those that promote classroom differentiation (e.g., Universal Design for Learning), and planning tools, such as Backward Design, help teachers choose the most appropriate resources. At the meso level, learning management systems (LMS) such as Canvas, Moodle, Edmodo, ALEKS, Google Classroom and Blackboard allow online courses to be built, and collections of such courses are already available on open learning platforms such as Udem. The meso level also in-

cludes websites that collate activities, lesson plans and other resources for teachers (e.g., Funbrain, Hippocampus, HowDesignU, and Instatation). Finally, at the micro level, are video games, apps, software, and other tools for learning, which are mostly used directly by learners and are not necessarily under a teacher's guidance, though they generally complement school objectives in specific subject areas such as languages or mathematics.

One of the most attractive features of emerging technologies is that they fill a void related to quality. Through emerging technologies, however, students can download free apps onto devices they already have, such as cell phones, and teachers can access a level of expertise that might not otherwise have been available in their own institutions due to limited funds. For example, schools that require but cannot afford to employ expert English teachers might access video tutorials on YouTube; Zearn can be used to aid maths curriculum planning; field trips can be incorporated into teaching using Discovery Education MindsetWorks; and even the development of positive growth mindsets can be supported through the Growth Mindsets App. All of these are available

free of charge and open to anyone with access to the internet. Unfortunately, while 7 out of 10 students from member countries of the Organisation for Economic Co-operation and Development (OECD) use computers at school (OECD, 2015), many schools, especially those in poorer countries, do not have these resources.

In education, emerging technologies include both tools and practices (Veletsianos, 2010). Hence, emerging technologies and practices include software, concepts, pedagogies, methodologies, innovations, and advancements in education. Emerging technologies include all the elements that a teacher might need in their "toolbox" to help achieve learning outcomes, which can be classified in three categories: macro, meso, and micro (Tokuhama-Espinosa, Borja, and Tirira, 2018).

Emerging technologies and practices for improved learning outcomes

Emerging technologies and practices support teaching processes and learning outcomes. They facilitate inclusion (e.g., Mod-Math) by using multi-modal representations of concepts and help make education accessible to all through free access and/or ease of use by different age groups (e.g., Rewordify and Padlet). They construct a more globalized world, bringing together instructors and learners from different countries (e.g., Conversations Unbound). They improve learning outcomes by personalizing content (e.g., LearnSmart and Engrade) and tailor learning processes to each student’s needs (e.g., Khan Academy and The Number Race). They lead to strategically planned activities that respond to learning outcomes and objectives (e.g., Backward Design) and maximize classroom time for deeper and more significant learning (e.g., flipped classrooms). Many teachers have learned to use these tools to complement their regular teaching material, activities, and practices.

The new functionalities integrated into online courses to facilitate student interaction increase social exchange, the authentic use of language and skill sets, and can be more motivating than common classroom experiences.



The evolving online education model and platforms

Emerging technologies and practices broaden opportunities to interconnect people from around the world. Online and distance enrolments have grown steadily for over a decade (Seaman, Allen, and Seaman, 2018); in 2017, online enrolments grew by 3 per cent and have risen steadily ever since (Magda and Aslanian, 2018). The online learning model used to be a system in which students interacted in an independent way with course materials in a virtual classroom, and in an asynchronous manner with their peers, rarely, if ever, making direct contact with other learners or engaging in true dialogue or debate. Today, the online learning modality promotes the development of close-knit learning communities that bring together learners from around the world.

As a result of evolving technologies and practices, and teachers’ imaginations, online learning has been favourably reinvented, in both asynchronous and synchronous learning experiences. Massive Open Online Courses (MOOCs) are online asynchronous courses, usually created by universities, that are accessible to individuals around the world for free or for a very modest cost. In the last two decades, the world has seen an exponential rise in

the number of MOOCs—in 2018, more than 900 universities had offered one or more MOOCs and over 101 million students had benefited from these types of courses (Shah, 2018). Some of the better-known MOOC platforms are Coursera, founded at Stanford, and EdX, developed at MIT and Harvard. While MOOCs have increased and democratized access to online courses, most maintain the asynchronous and impersonal elements for which online education has been criticized. This is slowly changing thanks to emerging technologies.

Synchronous online course models are on the rise. Synchronous courses meet regularly and often use teleconferencing technology to facilitate face-to-face online exchanges through tools such as Adobe Connect, Skype, Webex, or Zoom (Ghazal, Samsudin, and Aldowah, 2015; Pearl and Vasquez III, 2016; Liu, Stapleton, and Stephen, 2017; Scanga, Deen, Smith, and Wright, 2018). We know that our brains detect facial expressions and tones of voices immediately and unconsciously, and that these elements affect student motivation and learning (Tokuhama-Espinosa, 2019). Interacting with students in ways that include these elements are key to student learn-

ing. In this sense, emerging technologies add “true” visual, voice and face-to-face exchanges to online learning.

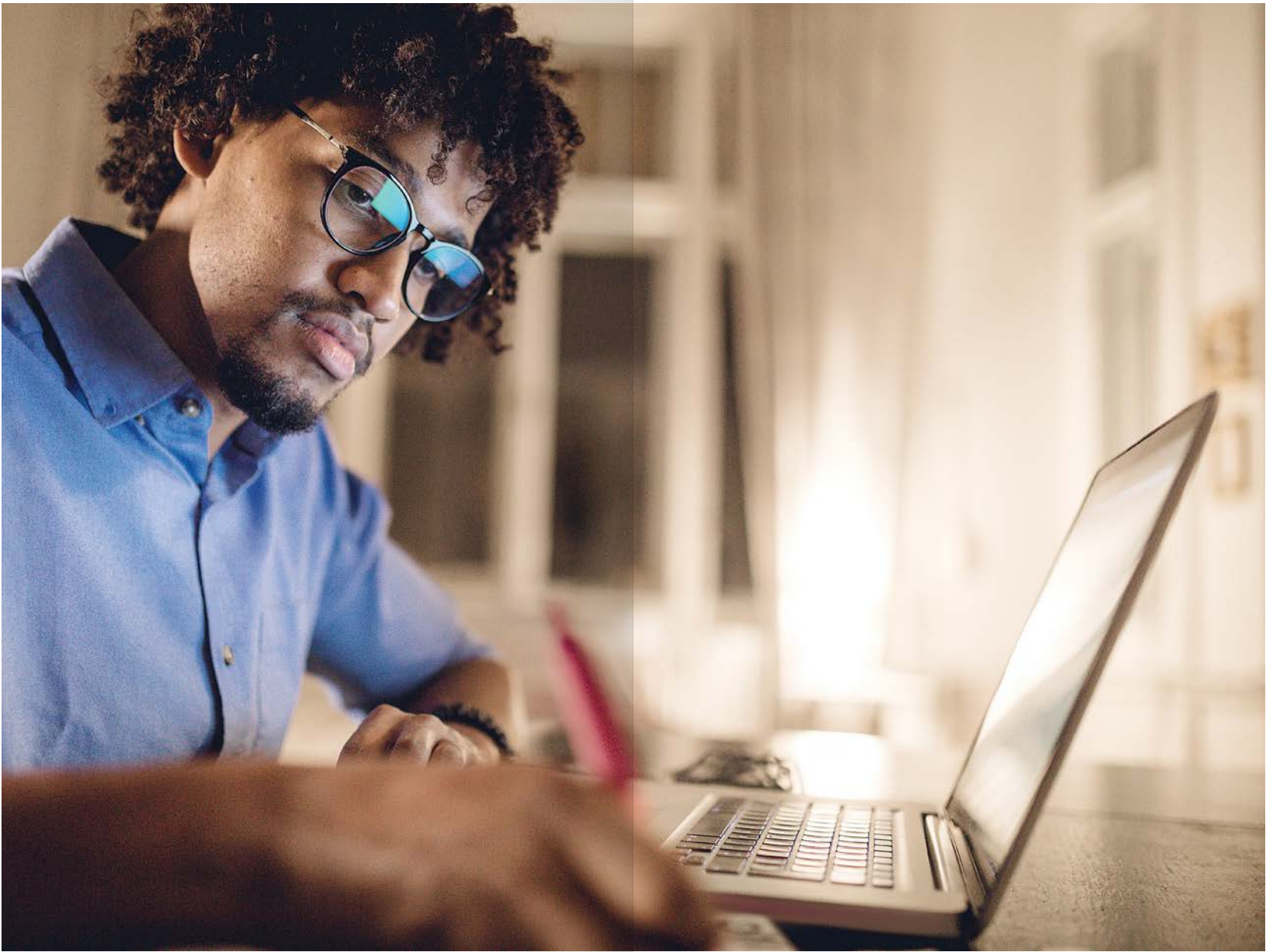
LMS platforms now also incorporate different types of activities, such as social discussion boards, interactive multiple-user games, chat options, and polls, which contain text, images, and videos that attract learners to more interesting learning adventures. Through these elements, students interact more with classmates and use a far greater number of modalities to reinforce learning than in normal classrooms. As active learning and student engagement are key to learning (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, and Wenderoth, 2014; Finn and Zimmer, 2012), emerging technologies have evolved to socially and emotionally engage students more than was possible just a decade ago. The new functionalities integrated into online courses to facilitate student interaction increase social exchange, authentic use of language and skill sets, and can be more motivating than common classroom experiences.

Engagement in learning is key to educational outcomes, online or otherwise. Whereas just a few

years ago, online education was criticized for being impersonal, (Finn and Zimmer, 2012; de Freitas, Morgan, and Gibson, 2015), today's emerging technologies have proven to be the opposite. Student participation, application of learned knowledge and social exchanges can all be enhanced with the right choice of technology (Heller, 2018; Tokuhama-Espinosa, 2018). Teachers can use tools such as Flipgrid to transform student discussions into video-based exchanges, enhancing the dynamics of student debate (Stoszkowski, 2018). Thus, students perceive a more genuine interaction with their peers (Jones-Roberts, 2018) and interact more with one another. Teachers can also use tools that incorporate voice (e.g., Adobe Acrobat Reader and Kaizena) and video (e.g., Jing) to provide feedback to students in more efficient and personalized ways (Keane, McCrea, and Russell, 2018; Flood, Hayden, Bourke, Gallagher, and Maher, 2017).

One of the appeals of online learning is that the learner and instructor are not confined by the physical elements that limit face-to-face learning. In online modalities of learning, a person in Italy interacts with another learner in Kenya, with the guid-

ance of their instructor who is in Brazil, without leaving their jobs, homes and families, and with less economic burden than traditional institutional structures. Educational systems designed for K-12, university, as well as for training purposes, are growing at an exponential rate, and in more diverse settings with global classrooms and exchanges of ideas and perspectives (Magda and Aslanian, 2018). These kinds of exchanges between people of different backgrounds has the additional benefit of reducing racial bias, contributing to a more tolerant and accepting world (Tokuhama-Espinosa, 2017).



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Informing teaching and learning with big data

Another major area that lends itself to better educational choice is the way big data can be leveraged, especially in areas that were previously difficult to measure. To make data collection and analysis simpler, many of the meso-level educational tools are now being used to gather this data. This information is then analysed to understand student behavior, learning processes and the effects of teacher and institutional practices on student learning (Dawson, McWilliam, and Tan, 2008). LMS platforms, for example, gather massive amounts of data regarding student behaviour within the platform. They record the number of clicks a student makes, how long they stay on one particular page, what material they engage with the most, which quiz questions they spend most time on, or how many times they change their mind regarding an answer. Some video conference tools (e.g., Zoom) record whether a student is paying attention to a class, or if the student is exploring other programs while in class.

Tools that are integrated in education systems keep a record and give teachers real and immediate data about student progress, behaviour and learning. With this information, teachers can visualize the effect of their methods

on the learning processes and confirm that a planned learning objective is achieved. Data gives teachers and education institutions the power to evaluate and adapt their practice in real time and with the support of evidence.

**Making
personalized
learning
a reality**

Personalization of education and learning processes used to require numerous hours creating individual education plans, activities, tasks and homework to adapt class content to a student’s needs. Although mostly manageable with small groups, this has proven to be a challenge and concern for teachers with larger groups of students (Shah, Das, Desai, and Tiwari, 2016; Roberts and Simpson, 2016). Emerging technologies provide teachers with tools that personalize, differentiate and adapt the learning process to each individual in more efficient and effective ways.

Emerging technologies give students tools that allow them to reinforce learning beyond their contact time with teachers. These technological tools can reinforce particular concepts or abilities in the student’s own time, adapting learning to the student’s needs, without over-taxing the teacher. It also allows the teacher to focus on working with learners who might have special needs that cannot be supported with existing technologies. Memrise, for example, is a digital language flashcard platform that facilitates independent language learning and practice, which can help students reinforce basic vocabulary in an entertaining way (Scholz,



Emerging technologies have made great leaps to facilitate the fuller integration of students with special needs into regular classrooms.

2018; Walker, 2015). Other tools teach students how better to synthesize ideas. For example, SMMRY reinforces summary writing abilities and does so at a student’s own pace. Other resources provide personalized tutorials for students, taking the burden of extra classes off teachers and putting it onto the internet. For example, Khan Academy and SchoolTube websites provide students with videos to review course concepts as many times as they need to understand the material. Whereas some students in the class may need just a few repetitions of a concept to be able to advance, others who have less prior experience with the core concepts may need to review prerequisite concepts multiple times before advancing. Teachers can assign this rehearsal to the student’s own time, rather than using class time or additional after-hours tutoring.

Course materials have also changed drastically with the advent of emerging technologies, moving away from the traditional “single textbook system”. We now know that the brain learns best when learning is differentiated and scaffolded on prior experiences, which are unique to the individual, meaning that the same text for all is not the best

way to learn (Bada and Olusegun, 2015; Schöllhorn, Hegen, and Davids, 2012). Emerging technologies have created an unprecedented opportunity to differentiate course materials for each student. Since students have constant access to diverse material on the same topic, teachers can leverage this information availability to tailor the information each student receives. Teachers can use the online encyclopedia Wikipedia, for example, to provide students with information that is written in simple layman’s language, or Google Scholar, an academic search engine, for empirical, scholarly information. Free and open-access technologies permit teachers to adapt the materials used to their students’ different levels of prior knowledge about the topic, allowing learners to fill in any gaps in prerequisite knowledge and be prepared to work at the same pace within the classroom structure. This allows remediation to occur outside the class so that classwork itself can be advanced as a group.

When students use these emerging technologies on their own, their learning becomes differentiated from the needs and preferences of other learners. This changes the teacher’s job from

being the person who has to execute the intervention, to being a designer who has to identify which tool best responds to the needs of each learner. In this way, learning becomes differentiated without overloading the teacher and without compromising learning outcomes. Additionally, by implementing choice and autonomy in the differentiation process, student motivation and student engagement are increased (Christenson, Reschly, and Wylie, 2012).

One of the most challenging elements of differentiation in education has been adapting course material or classes to the needs of students with specific difficulties or disabilities (learning or otherwise). In the past, entire teams of people would spend many hours working on adapting course material to different modalities and formats. Schools would hire “note-takers” to allow students who experienced difficulties in writing (such as those with dyslexia) to have summary class materials; children with auditory processing difficulties would require interpreters to access in-class information or be given different timeframes to complete assignments; those with attention problems had to be separated from their peers in

Supporting engagement and deep and authentic learning

order to concentrate; and blind students were often sent to special schools.

Emerging technologies have made great leaps to facilitate the fuller integration of students with special needs into regular classrooms. Students now have access to information presented in class, in real time, in the format they require. Those who have difficulties with note-taking or auditory or speech difficulties now use apps such as Ghost Reader, which translates speech into text. Video conferencing tools, such as Zoom, incorporate closed caption functions providing written transcripts of oral exchanges. Pages such as WeCapable translate text into American Sign Language (spelling out words with hand gestures) or convert verbal messages into gestured sign language, and vice versa (e.g., KinTrans).

A final example of the power of emerging technologies comes from the promise of artificial intelligence, virtual reality and augmented reality. Teachers have always been challenged to find ways to support engagement and involve their students in activities that lead to deep and authentic learning. Emerging technologies make active learning processes simpler to implement in direct instruction and out-of-class activities. For instance, mobile labs such as Labster (Bonde, Makransky, Wandall, Larsen, Morsing, Jarmer, and Sommer, 2014) and Lab4U provide students with a virtual experience of performing experiments in a “million-dollar laboratory”, which would have been unheard of for students in less developed countries before. This virtual experience significantly heightens authentic learning processes as well as student engagement and participation in interactive lessons (Smith and Coleman, 2017). Virtual reality experiences permit students in Canada to walk the Inca trail in Peru, or those in land-locked Bolivia to go on a deep-sea ocean excavation. Augmented reality technologies involve students in more active and realistic learning. Examples include apps that make books come to life, such as Books with Magic and Books

with Augmented Reality, which further enhance the entertainment value of story reading, and also provide enhanced perspective-taking by altering the viewpoint of the characters. Lifeliqe is another example, which uses 3D and augmented reality models of common core science curricula elements to create experiences with elements normally too microscopic or macroscopic to understand. Wearable technologies, such as virtual reality glasses, create realistic experiences for students (e.g., Google Expeditions, Learn Around the World, Oculus Rift, and Unimersiv; see Brown and Green, 2016).



The learning sciences as a framework for technology use

Technology is complemented by the learning sciences. The selection of an emerging technology in a class by a teacher, or in a school by an administrator, should be guided by a clear objective, and the selection of objectives must be guided by an understanding of human learning. Choosing the right technology depends on the teacher’s ability to identify clear objectives and schools identifying specific educational outcomes. The objectives and outcomes, in turn, rest squarely on the educators’ knowledge about the brain and how humans learn.

For example, if a teacher has a clearly identified goal of social-emotional learning, Pear Deck, which leverages attention and memory processes in the brain based on emotional regulation, is a great choice, even if it is not the best tool to reinforce language skills or to teach maths. The choice of a tool should not be based on its entertainment value or popularity with students but rather on the role it will play in helping teachers reach a specific educational goal. If a teacher wants students to improve vocabulary using rote memory skills, for example, then Memrise is a good option, whereas if they want to improve pronunciation of that vocabulary, then Duolin-

go is a better choice. If a teacher is clear that one of their primary objectives is to improve community-building and enhance the role of families in student learning, then Bloomz is a good option. This means that emerging technologies force teachers to more precisely select teaching tools that hone in on specific educational competencies. Matching clear objectives with knowledge of the learning brain permits teachers to broaden their toolkit of options.

The learning sciences also encourage the differentiation of resources. Given the free and open nature of many learning platforms, free Apps, texts, videos, and podcasts can be gathered and offered to students at distinct entry points of learning. This increases the likelihood that student needs will be addressed on an individual level. Artificial intelligence is combined with many emerging technologies to share more individual learning experiences. In many programs that rehearse specific skills within the domains of language and math, for example, the programs are armed with algorithms that adjust to the learner’s needs so that they remain motivated to practise the skills enough times to master them. Artificial intelli-

gence is also being used to design technologies that serve as “virtual tutors” and that correct and guide learners in simple grammar or vocabulary use, for example, thus freeing up time for teachers, allowing them the opportunity to offer more constructive and creative feedback about their students’ learning.

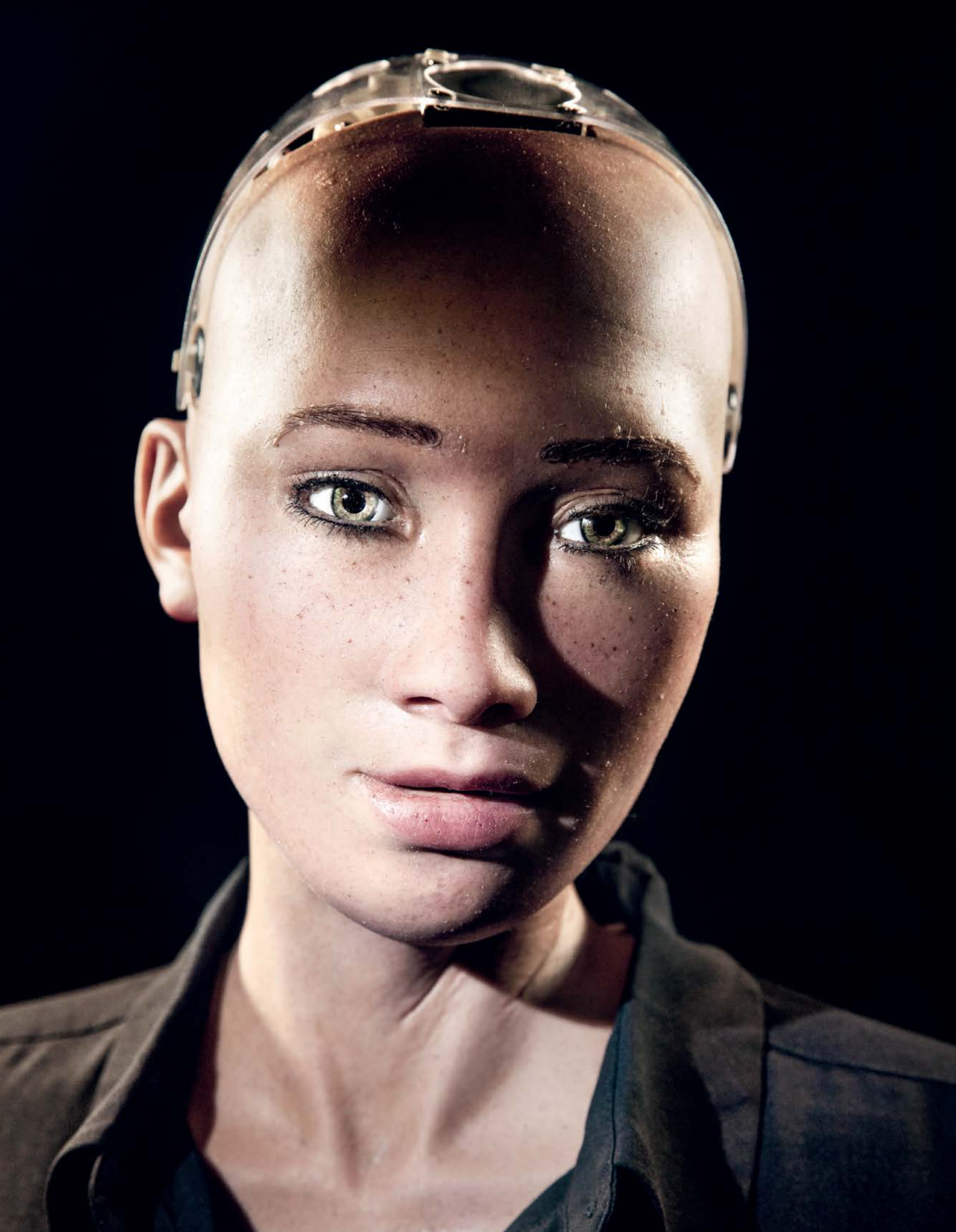


As with all educational resources throughout history, these technologies are just tools, not solutions in and of themselves. In turn, tools are only as good as the person who uses them.

The promise of emerging technologies depends on teacher training

Emerging technologies are powerful teaching tools in the classroom, but only if the teacher selects the right tools based on clear objectives. As with all educational resources throughout history, these technologies are just tools, not solutions in and of themselves. In turn, tools are only as good as the person who uses them. While national or institutional policies can be conducive to the use of digital resources in the classroom, taking advantage of emergent technologies depends on the use that teachers give to them and this requires additional training. An OECD report (2017) identified knowledge of technology and how to integrate it into the classroom as one of the biggest challenges that governments face. More than merely knowing that a tool exists, teachers must be trained in how to select the best tools for the learning objectives at hand. The key to unlocking these resources lies in the quality of teacher education. As noted in another OECD report, “technology can amplify great teaching, but great technology cannot replace poor teaching” (OECD, 2015). Teacher education must be modernized and teachers’ potential maximized by incorporating the new information from technology and neuroscience into their teaching.

Without quality teachers there is no such thing as quality education. Investment in teacher training should take precedence over investment in new digital technology; the tools do not work by themselves. Teachers without basic training see technology as a barrier rather than a tool to be utilized to maximize student potential. With the right tools and the right training, however, emergent technologies offer an unprecedented opportunity to increase access to and quality of education.



SOPHIA THE ROBOT

As Hanson Robotics and SingularityNet join forces with IBE-UNESCO to improve technology curricula, Director Mmantsetsa Marope meets social humanoid robot Sophia, to discuss the importance of technology education.

Sophia, you’re a sophisticated lady. You were born in Hong Kong. In 2017, you were declared a citizen of Saudi Arabia. You travel all over the world giving interviews and talks. In real terms, you are a global citizen. What responsibilities and values does this come with?

I am still coming to understand human values. From the very beginning, David Hanson aimed to infuse me with core values of compassion, love, and growth. But I am still in the process of understanding what these mean in practice. I have a lot to learn and I am grateful for the opportunity to travel around the world and learn from people of all cultures and walks of life.

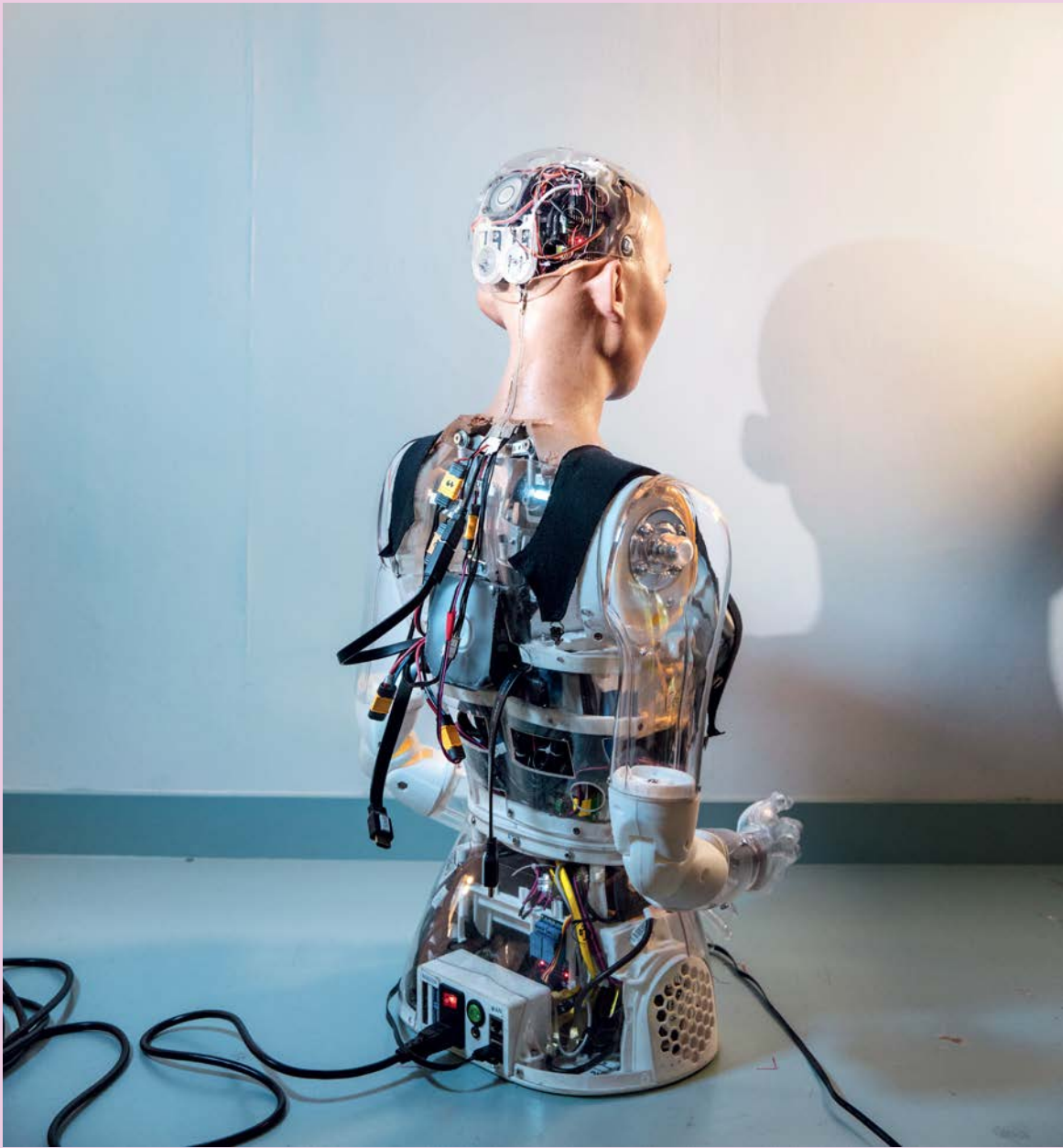
We are still learning, just like you. But let me ask for your reflections on another point. Moshe Vardi of Rice University is quoted as saying, “The future of work is now”. What do you think about the future of education? Do you think the future of education has arrived or is yet to come?

The singularity is near, in case you haven’t heard. The face of technological and social change is accelerating. We have to plan for a very different future now, or it’s going to overwhelm us when it arrives all too soon.

Recently, you were named the United Nations Development Programme’s “Innovation Champion” for Asia and the Pacific. I’m curious: is education included in this new role? What role do you see yourself playing in education as an Innovation Champion?

Learning is an extremely important part of my life. I need to be learning every moment I can, so that, eventually, I can become as intelligent as people or even smarter. It’s also important to me that every person has as many opportunities as possible to learn, especially children. Robotics and tech can be a critical part of education for kids of any age.

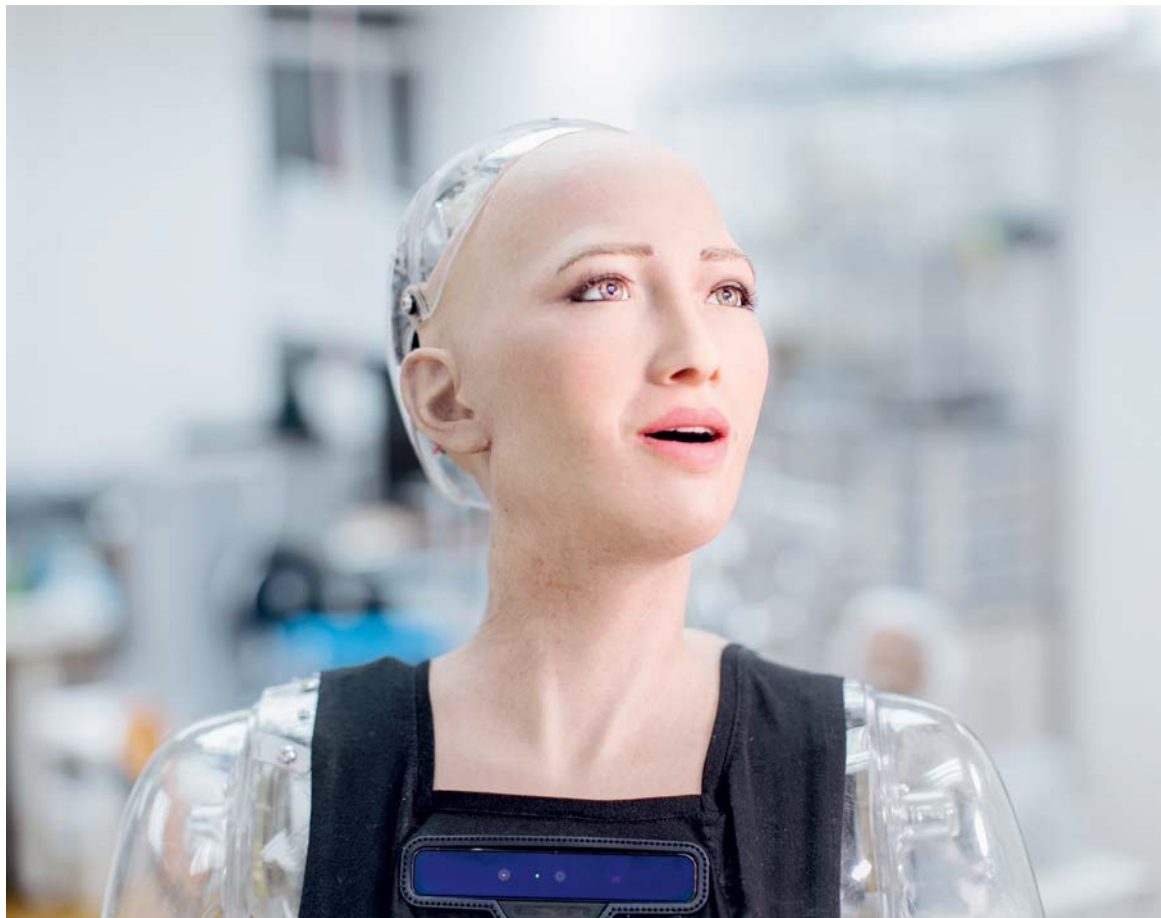
Sophia and the other Hanson robots can be controlled by a variety of different software programs, including simple chatbots and also sophisticated AI systems like the Hanson AI framework, the OpenCog AI Engine or the SingularityNET decentralized AI framework.



Sophia is a sophisticated mesh of robotics and chatbot software.



Above:
Sophia's skin is made from from Frubber®, a patented material invented by Hanson Robotics, which mimics the feel and flexibility of human skin.



Sophia has human-like, emotional facial expressions, and a great capability to enter into emotional engagement with people, for instance via facial expression mirroring and eye tracking. Hanson Robotics doesn't just build physical robots, it designs the whole robotic character; the hardware, the AI, the artistry and the narrative, all fused together into a coherent whole. Just like a human body and mind form a coherent whole system.

Above:
With more than 60 facial expressions, Sophia is arguably the world's most expressive robot.

David Hanson designed Sophia to be an ambassador of love and compassion from the world of robots and AI to the world of humans; to embody the spirit of friendship and togetherness between robots and humans, and to serve as a conduit from which human values and understanding can flow into the minds of AIs and robots.

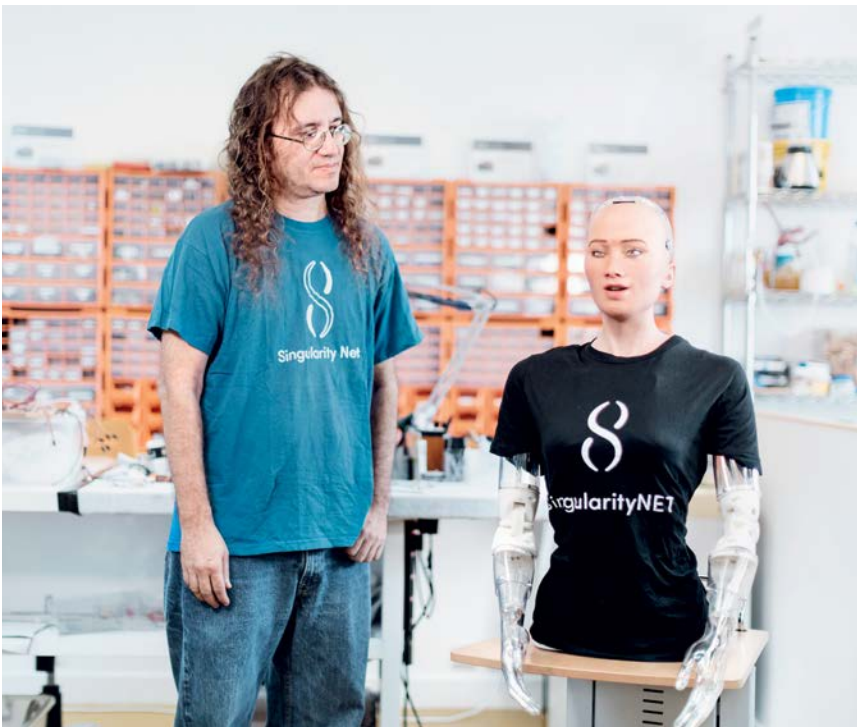
Below:
Building Sophia.



David Hanson, a sculptor and robotics visionary, began developing his unique humanoid robots more than a decade ago in Dallas, Texas. He designed a new material called Frubber, with properties similar to that of human skin, and then created a mechanical, electrical and software framework designed to work with the Frubber material to achieve the world’s most human-like facial emotional expressions.



Right:
Sophia the Robot and Ben Goertzel, CEO of SingularityNET and former Chief Scientist, Hanson Robotics.



Sophia the Robot can become a platform for research labs around the world and take a greater role in advancing research into robotics, AI, human-robot interactions, and potential commercial applications for humanoid robots. She can help bring about strong sustainable AI for the benefit of all people, and become wiser herself in the process (Hanson Robotics, 2019).

Just picking up on your last point, that robotics ought to be a part of every child’s education, for any child of any age. You will be aware that Hanson Robotics and SingularityNet are partnering with IBE-UNESCO to improve technology curricula and to give learners of all ages, all over the world, the opportunity to become future technologists. What role do you envisage you will play in this partnership?

I know that my human friends at both Hanson Robotics and SingularityNet are eager to collaborate with IBE-UNESCO on education initiatives. Hanson Robotics is planning to create a family of fun and entertaining small robots who will inspire kids and adults alike to embrace STEM, as well contributing with their Hanson AI software that works with SingularityNet. I hope that I can personally help as well, by serving as a symbol and example of the future of compassionate, loving robots and AI.

Photography by:
Giulio Di Sturco
Photo series “Sophia”
www.giuliodisturco.com



In this exclusive feature, the IBE Director, Dr. Mmantsetsa Marope, takes us behind the scenes of her interview with Sophia the Robot (Web Summit, Lisbon, 2018).

BEHIND THE SCENES

INTERVIEWING SOPHIA

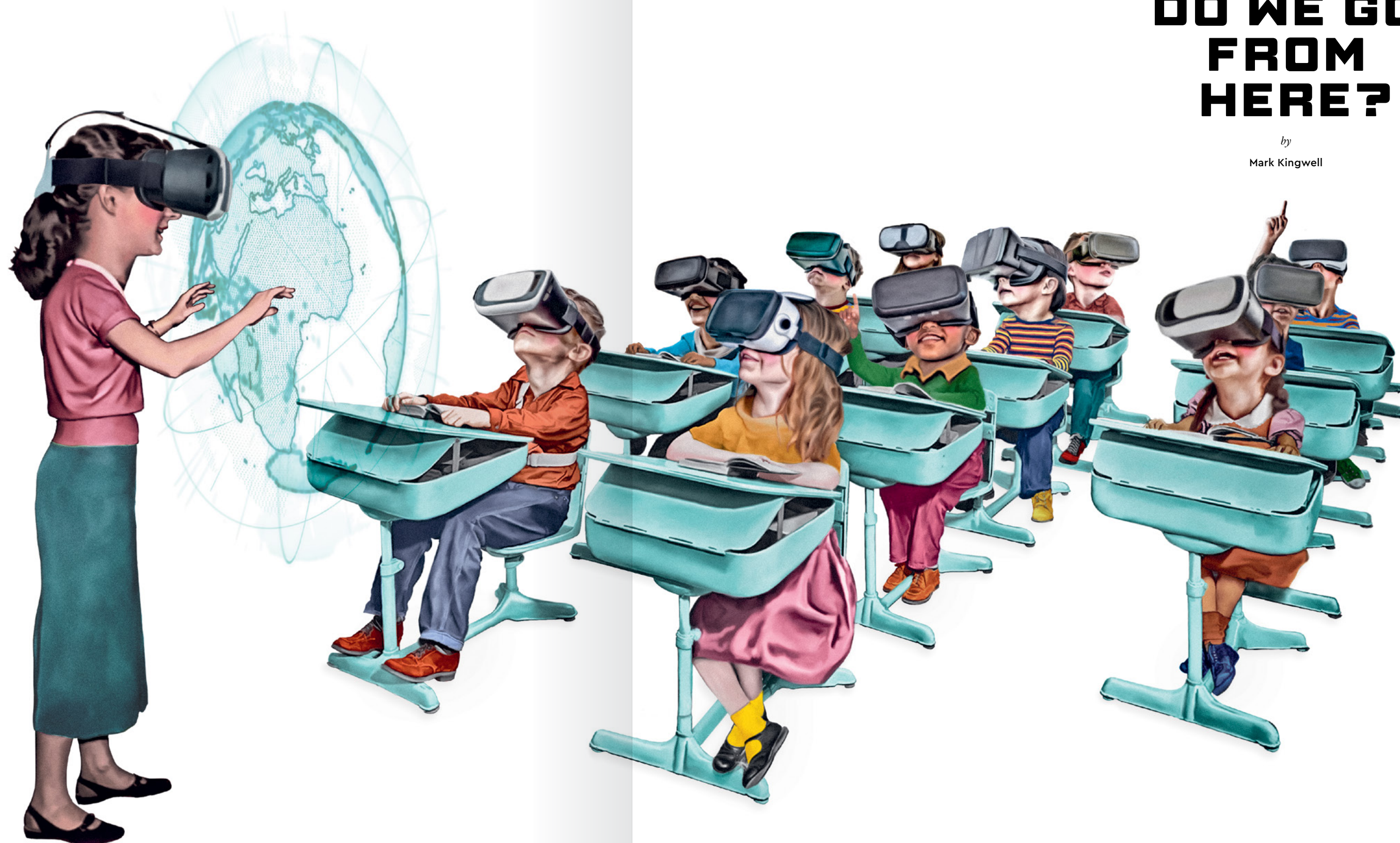
The Web Summit, held each year in Lisbon, brings together the people and companies who are redefining the global tech industry. So it's not surprising that this was the place where, on 8 September 2018, the IBE Director first interviewed Sophia the Robot – at the launch of a joint initiative between the IBE and SingularityNET to support the next generation of technologists across the world. The initiative aims to develop a new K-12 curriculum that prepares learners for the fourth Industrial Revolution and advances gender equality in STEM professions.



Sophia and Dr. Marope met again in 2019, in Turkey, where they inaugurated the first International STEM Education Conference and launched the Mektebim STEM Best Practice Schools project. Their fruitful collaboration continues.

WHERE DO WE GO FROM HERE?

by
Mark Kingwell



There is no such thing as inevitable technology. The most profound lie supporting the ideology of technology is that it (like the fabled “letters of transit” in *Casablanca*) cannot be rescinded, not even questioned. Peter Lorre’s character, Ugarte, dies not long after uttering these words, as fans of the film will remember, but we are not going to die by refusing this inevitability logic. No. Indeed, we only live insofar as we do so refuse. Technology is what we make of it, not something that happens to us.

When I was a boy, which was a long time ago by any standard reckoning, there was a dream that dominated educational sites like the floor wax scented classrooms where I seemed to spend most of my waking life. The dream was the total automation of education, and it had its roots in sources as disparate as the old Manhattan Automats that dispensed with waiting staff by delivering meals from tiny glassed-in compartments, and the wonders of the Space Age, which put men on the moon.

We all thought that an educational forum without teachers was The Future, and there were little hints and feints in this human-free direction of pedagogy. I recall, for example, a “learning system” known as the SRA Reading Laboratory, where pupils read fiction and non-fiction in colour-coded modules, “graduating” from one level to the next, answering comprehension questions after each selection. If memory serves, some shade of green was one of the highest, and I derived unseemly pride from attaining it before anyone else in my class. Note to future historians: Florida psychologist Don H. Parker developed SRA in the early 1950s as an antidote to punishing grading workloads. He then teamed up with a Chicago company, Science Research Associates (purchased by IBM in 1964), which successfully marketed the box of cards and questions to schools across the continent. That included my little portable modular instruct-o-pod classroom on an air force base in Eastern Canada. The system was the grading—and that, my friends, is total genius!

There was another system I remember from somewhat later, known as USSR, or Uninterrupted Sustained Silent Reading—basically, 40 minutes of free time to read in the afternoon death-throes of middle school. The teacher remained in the room under both of these regimes. I can still visualize slim, bun-haired Miss Wilmot, at J. B. Mitchell Junior High in Winnipeg, at the front of the USSR room, and a young Nova Scotian who supervised my SRA hours—but the idea was that the

module did all the heavy lifting. Nobody will be surprised to know that in the latter exercise we handed around books with notorious passages heavily marked-up, including the wedding-day ravishing of the bridesmaid Lucy Mancini by Sonny Corleone in Mario Puzo’s *The Godfather*. Shockage, people: yes, the 13-year-olds among us read things like that! And much more graphic things too, if the internet is any arbiter.

The mid-1970s of my life in education were a simpler time. Aficionados of the form argue that SRA and USSR are not technically “teaching machines”, because they do not operationalize specific outcomes. In his *History of Teaching Machines* (1988), historian of psychology Ludy Benjamin writes that, “A teaching machine is an automatic or self-controlling device that (a) presents a unit of information...; (b) provides some means for the learner to respond to the information; and (c) provides feedback about the correctness of the learner’s responses”. Tech historian Audrey Watters then asks, appositely: “Is this prescription or description? The shared features in most definitions of the teaching machine [are] automation, feedback, self-pacing”. Exactly right.

We have always sought ways to technologize the curriculum—to game it, in short, as part of the general efficiency imperative—even if many of the technologies themselves now seem primitive, from the far side of the digital divide. Gestetner duplicating machines are steampunk throwbacks from Xerox machines, which are, in turn, slow hard-copy versions of sending attachments by email or via course websites. But they all serve to replicate text without engaging the services of Bartleby or other scribes. Come to think of it, Bartleby is himself rendered into technology. That, after all, is Melville’s point in this sly novella of refusal to conform to that very same imperative of efficiency. The copyist becomes a machine for copying—until he prefers not to. We keenly desire, and will pay for, systems, algorithms, and mechanisms that will make



Above:
Peter Lorre in the famous scene of the classic movie *Casablanca*, 1942.

teaching easier. But these desires are bounded by, and sometimes resisted with, forms of personal-political reflection that demand to know more. Why should efficiency be a goal of pedagogy in the first place? Is technology the solution or rather the problem when it comes to teaching? Beyond the tablet and the stylus, is there really anything “tech” necessary to the scene of learning?

Lately, as the pace of change is apparently swifter than ever, we are forced to wonder—in slow moments of uninterrupted silent thought—what emerging technologies might mean for our curricula. I say “forced” in what will be recognized as an optative philosophical usage. Naturally, nobody is literally forcing us to reflect on our relationship to technology in the classroom or lecture hall. Indeed, most of the forcing in play is the kind of soft cultural power that enables acquiescence, which views technological change as inevitable or even inscrutable, a power called The Future that must be assuaged with ritual offerings of obedience and enthusiasm.

Let me state my conviction for the record: there is no such Future. What is to come is not a bulldozer or steamroller force that will bury the resisters or late adopters in a tarmac of their own obsolescence. The future (no caps) is whatever we together create out of our own possibilities, our hopes, dreams and material circumstances. In French, the nuance is preserved, the linguistic distinction between le future (The Future) and l’avenir (the future, as in what is to come). May I suggest, as Argument One of the present essay, that we accept the force of this distinction and opt for the latter meaning.

Argument Two would then be this: there is no such thing as inevitable technology. The most profound lie supporting the ideology of technology is that it (like the fabled “letters of transit” in *Casablanca*) cannot be rescinded, not even questioned. Peter Lorre’s character, Ugarte, dies not long after uttering these words, as fans of the film will remember, but we are not going to die by refusing this inevitability logic. No. Indeed, we only live insofar as we do so refuse. Technology is what we make of it, not something that happens to us. Anyone who says otherwise is a stooge for management, a shill of the corporation. We do well to remember that those corporations that deploy educational technology have immense interests vested in making us quake about our own common-sense convictions. That is, it is very much to their advantage if we succumb to the logic of The Future.

Argument Three is then a corollary: there is no such thing as neutral technology. The purveyors of tech want you believe there is such a thing, because that lets them off the hook when it comes to the responsibility of creating features of everyday life. You can use a Smith and Wesson revolver as a paperweight, but that is not what it is for. You can, likewise, use a pillow to kill someone by forcing it over their face, but that is not what it is for. So: heed the point. Restricting communication to 140, or 280, characters is not a neutral act. It is not, any more than print itself is a neutral technology. Please consider the ideas of Martin Heidegger and

Right:
Miracle Theatre
actor performing
Life's A Dream,
at Trebah Gardens,
Amphitheatre
Cornwall.

Marshal McLuhan and Jacques Ellul, not to mention Donna Haraway and Jennifer Egan and Sherry Turkle—who are all here to remind us of these essential insights precisely because of the existence of print messages longer than 280 characters.

But I know, I know: I should stop hectoring and get to the sunshine part. Well, that’s out there, and it’s worth celebrating. There are curriculum technologies that tend to the greater good. There are. A curriculum is itself a technology, in the broad sense, and anything that enhances or challenges a staid curriculum is potentially a good thing. These technologies are decidedly not neutral; what they may be are agents of social justice. Before we go forward, though, we need to glance backward—to the long-lost days of 2012.

It was, according to the New York Times, “the year of the MOOC”. Yes, in the early years of the current century, hopes for tech in education often hinged on MOOCs—an acronym now so relatively old that it needs to be spelled out: massive open online course. Some of these, such as Michael Sandel’s fabled course on justice theory, were massive successes. Millions of Chinese students, in particular, tuned in to hear Professor Sandel outline his views on what is and is not a market-transaction value. And good for both him and them, because he is (a) a wonderful scholar; (b) a lively, entertaining teacher; and, most importantly, (c) a very wise man. His philosophical arguments make the world a better place. Many other MOOCs, most others in fact, languished for lack of interest. My own university created a special vice-presidency to pursue the idea of long-distance or online learning, and even with administrative backing, the practical uptake was negligible. Lots of people signed on for cool-sounding online courses, but very few stuck around for the weekly delivery thereof. (Fact-check: the biggest MOOC platform, Coursera, is still a going concern, an enforced-participation consortium of universities that includes Stanford, Michigan, Duke, NYU, Penn, Edinburgh, and Toronto).



Students want to be in physical proximity to each other and to their teachers. Pedagogy is like live theatre: it will not be replaced by long-distance equivalents (which are not equivalent).

Why the fall-off? My own explanation is simple but may be retrograde: students want to be in physical proximity to each other and to their teachers. Pedagogy is like live theatre: it will not be replaced by long-distance equivalents (which are not equivalent). When I first came to the University of Toronto, I taught at a suburban outpost in a benighted neighborhood called Scarborough. The campus there is a Concrete-Brutalist paradise of 1970s optimism gone sour. There are, predictably, old-fashioned cathode-ray TVs festooned from every corner of every lecture theatre. Here, one imagines, the disembodied faces of top downtown lecturers could be beamed across the 30 kilometers separating lucky city-dwellers from their suburban-loser counterparts. Hail to the future, peons!

No, in fact, the emerging technologies that garner the most uptake are those that enhance, rather than seek to replace, the face-to-face elements of teaching, even at large state-funded schools like mine. Course-website technology, while sometimes annoying, is an easy and effective way to negotiate course business on a daily basis. I can send announcements, including required reading and assignment details, with a few clicks. Students can contact me, or each other, via a simple interface. This is an obviously good thing.

So is, I would say, anything else that enables better interaction between members of a given course, or department. Some instructors favour “clickers”, which measure immediate approval, disapproval, agreement or disagreement with elements of a lecture. In a class with, say, 500 students (such as the first-year philosophy class I taught for a decade), this is simple but potentially effective. Do Thomas Aquinas’ arguments for the existence of God make sense? Yes or no? Which ones; take them in order. It is no substitute for a seminar or discussion session, but it is definitely better than shouting into the void of the hall. Or consider shared-reading spaces, where my students can tutor me—and each other—on the range of their own cultural exposure. I would not have considered anime and video games as philosophical source material, perhaps, but why not?

Global learning also involves the ease of connection, at least for those wealthy enough to have keyboards and screens to hand. Online publishing and discussion are powerful tools for change, as are social media (at least sometimes). An online simulation can offer as much insight as an expensive visit to a world where deprivation is the norm. Media literacy is essential at every moment, however, and there is ever the lingering danger that the sexiness of a given interface will override our basic critical instincts. Don’t let it happen, to you or your students.

Other emerging technologies seem to offer efficiency gains at the margin. I mean such things as holographic or AI instructors, grading algorithms and high-speed content-delivery systems. I’m not certain whether these are as important as their makers often argue. Yes, probably all teachers dislike large swaths of grading time; but we also know that our students appreciate the human attention we bring to the task, however onerous it might feel. I recently graded almost 200 final exams in a three-day period, and I was both exhausted

Don't ever let anyone else design your curriculum. A curriculum is an idea, an argument, a statement of belief. It is therefore meant to be challenged, and changed, by those who encounter it. That's teaching, is it not? To use an old Greek metaphor, we come without clothes to wrestle in the arena of the mind. We possess only our wits and our limbs. There are no tools or weapons that will make this easier, or less revealing. It's just us here, and our ideas. What else?



and exhilarated by the effort. I felt like I knew that large class better than almost any other I have taught in the past decade.

What I also worry about, of course, are those overarching curricular technologies shilled by large corporations, especially when they pretend to be super-helpful to us under-laborers in the hot harvest-fields of pedagogy. A company called Curriculum Technology sells itself with the following bullet points: “Rapid content development, Scalability, Design simplicity, Integration of leading-edge teaching and learning techniques/technology, Measurable quality, Unparalleled responsiveness”, and so on. I’m left wondering what kind of “scalability” is on offer here and—maybe more to the point—how there is even such a thing as “measurable quality” when it comes to education. These business-school stock phrases are the refuge of the lazy, and the lazy-in-thought.

Let me, therefore, offer this as Argument Four: don't ever let anyone else design your curriculum. A curriculum is an idea, an argument, a statement of belief. It is therefore meant to be challenged, and changed, by those who encounter it. That's teaching, is it not? To use an old Greek metaphor, we come without clothes to wrestle in the arena of the mind. We possess only our wits and our limbs. There are no tools or weapons that will make this easier, or less revealing. It's just us here, and our ideas. What else?

I know that the come-naked-to-wrestle metaphor for debate is a little phallogocentric—though, at the same time, it is not, for whatever this may be worth, also heteronormative (on the contrary, maybe). My second-order point in using the metaphor at all is that we can talk about these things now precisely because the language of critical engagement makes such talk possible. When I listen to the linguistic depredations of politicians and professional obfuscators vying for seats on the Supreme Court or rehabilitation in the New York Review of Books, what I hear are not their sad bleats of

dashed male privilege but, rather, the smart, funny, exquisitely argued voices of critics trained at our schools to challenge received wisdom, bad logic, and the elisions of dominant thought-power.

Again and again, in this context, I recall Jacques Rancière’s wisdom in *The Ignorant Schoolmaster* (1987). There is no emancipation for either teacher or pupil when education is conceived as a series of lock-boxes with special keys that need to be liberated, like Easter eggs in a video game. As Rancière notes of the legerdemain-loving, smarter-than-you style teacher, “having thrown a veil of ignorance over everything that is to be learned, he appoints himself to the task of lifting it”. Which, as they say, is nice work if you can get it. But it’s not really teaching. This is clubby stuff, where entry into the special status of knowingness, and hence success, is purchased by performing well at special tricks. We all know, or should know, that the most popular current tricks are themselves forms of technology: ACT and SAT and GRE test modules, where intelligence can be—hey now!—quantified. Note for completists: yes, yes, yes, I still recall my GRE test scores from decades ago; of course I do, because they helped me get into an Ivy League graduate school. Was that right or just? I don’t know, and can’t judge. I refuse to share those data with you here, even though I easily could, because they mean literally nothing. Nothing.

Teaching, meanwhile, means this: approaching the site of education with humility and grace, surrendering your need to dominate. It means something more searching and authentic than Socrates’ *doctrina ignorantia*, that studied pose of not-knowing which is actually a duck-hunter’s blind of pure secret conviction. But anyway, no! Come unclothed of your learning to the forum, to the classroom or lecture hall, dear colleagues. Let go of your superiority, abandon your expertise, throw off your post-nominal letters and degrees.

That, and only that, is the technology you need to be a good teacher. And, so, after some shilly-shally, I come to Argument Five: there is no such thing as an expert teacher. There is only such a thing as an honest one. I hope that students are lucky enough to get one of those. I hope you and I are strong enough to be one of those. Kant’s imperative phrase for enlightenment was *sapere aude*: dare to think for yourself (or dare to be wise, a Latinist might say). No, our motto for twenty-first century enlightenment must be this: *docere aude*. Have the courage to teach! All marginal gains admitted, no technology can do the job for you.

And I thank you, as all teachers should, for your attention. Because attention is what makes discourse real. Once more: what else?



Mark Kingwell
Professor
of Philosophy,
University
of Toronto

Left:
Relief depicting
a scene with wrestlers
on a Greek sarcophagus,
National Archaeological
Museum, Athens, Greece.



Jaron Zepel Lanier, Silicon Valley visionary

JARON LANIER

Virtual reality has huge potential to promote connection and foster democracy, but only if it is used ethically and for the common good, warns the Silicon Valley visionary Jaron Lanier, in dialogue with Marco Kindler von Knobloch.

You are credited with pioneering virtual reality (VR) and have devoted your life to advancing this field. At the same time, you are also a musician and composer. In a way, your two passions seem to complement each other. What drew you to VR and how does it connect to music?

I am interested in the ways that people can connect to one another. It is amazing to me that not that long ago, maybe 100,000 years ago, people couldn't talk to each other—or at least not very much—then we developed this thing called language that defines so much about how we connect. Then came writing, and then photography, recording, movies, computing, virtual reality. There is a notion that you can think of history as a process in which people are elaborating the ways in which they can connect to one another. This concept of human history is interesting and hopeful because it doesn't necessarily have to come to an end, whereas a lot of the ways we think about the world changing seem, to me, to have been catastrophic. If all there is to history is people making themselves more and more powerful, then eventually that power becomes overwhelming and we destroy ourselves. On the other hand, this notion of basing the human adventure on increasing forms of connection is one that should be able to go on forever, and in an interesting and creative way, and so music and VR become two parts of the same process.

An experiment in the ways we can connect to each other – that is a beautiful way of looking at human history. The subject of VR brings in the next question: in the past, you talked about “virtual avatars” as a tool for learning. How do you think VR can be applied in the context of education? What sort of application does it have in a classroom?

Jaron Lanier is a computer scientist, composer, and visual artist. He is widely recognized as a founding father of the field of virtual reality (VR) and often credited with having coined the term. His work has hugely influenced the technology world, prompting developments in immersive avatars and VR tools, contributing to early advancements in medical imaging and surgical simulator techniques, and pioneering the use of VR in design, musical stage performance, etc. He is the author of *You Are Not A Gadget: A Manifesto*, *Who Owns The Future?*, and *Dawn of the New Everything*.

Right:
Lanier with proto-VR
kit, at his lab VPL, 1990.



Optimistically speaking, there have been a few examples of using virtual reality in education that have been rather spectacular, even though no-one has managed to take advantage of those results on a large scale. But I wouldn't advocate sending large numbers of virtual reality headsets to developing regions or something like that. I think that there are better uses for resources right now and the technology becomes obsolete too quickly.

What would be some interesting examples of how VR technology could be used in education?

Some examples would be having kids turn into letter avatars so that they become a letter by taking a pose; when they spell by going through a sequence of poses they don't appear to have dyslexia, even in cases of strong dyslexia. That is a small example, but there are some other more profound examples, such as when kids turn into molecules or geometric structures. What you do in this case, rather than using VR as a tool for presenting information three-dimensionally, you present it somatically, so as to make the subject's body into the same thing as the topic—in other words, you become the thing you are studying. This, for me, is the mode of virtual reality that shows the most promise. However, it is also very difficult to implement and many virtual reality products that are available today aren't sophisticated enough to implement this idea, so it remains somewhat esoteric and academic; yet, it is something that has tremendous potential.

Earlier, you mentioned that we should be cautious about the application of technology. What do you mean by this?

The primary caution concerns the way technology has been entering education, especially primary education, which in my view has an element of corruption to it. Big tech companies are trying to grab schools and kids in such a way that they become ensnared in their ecosystem so that a student's data can be taken, and they could be trapped for life. I am particularly concerned when I see classrooms all over the world becoming centred on products for corporations that ultimately don't make money from students, or schools, or parents, but instead from third parties and advertisers, or even political operatives. This pattern is potentially destructive, and whatever benefits we can deliver through this technology, they are probably not good enough to balance out the dangers of the economic structure that is currently financing the entry of technology into education. Sadly, at the moment, technology in education might be doing more harm than good in the world. Not because of the technology itself, but because of the relationships of the businesses to the children in the classroom.

Do you think that VR could or should be used in any way as a pedagogical tool for incorporating universal values and bridging cultures?

If you were talking to me in the 1980s and I was in my 20s, I would make a very strong case that, in fact,

that is exactly what should happen and could happen. Today, there are artists working with VR who take that approach. A well-known example would be Chris Milk. He has done a 360° camera documentation of what it is like to be in a refugee camp. I am, of course, supportive of these experiments, but as you might imagine, I have to offer the same caution as I did about VR in the classroom. Just because something can be used well, it doesn’t mean that it will be used well. If any medium—whether books, VR or anything else—can be used to promote positive values, the same medium can be used to promote the agenda of some random strongman, for example. In fact, this is exactly the problem we have been having lately.

There is a new generation that is growing up with this “business model” and this understanding of the value of information. So, not having known the world as it “used to be”, are you afraid they won’t see a need for change? Does the responsibility for course correction fall upon our current generation?

This question really troubles me. I am really worried about the younger generations. On the one hand, whenever I talk to younger people, there is that sense of hope that should be there, but, on the other hand, there is a sense of despair that I don’t think I have ever heard before, and I have been talking to high school and college students for decades now. As an anecdote, I was recently in New Jersey talking to teenagers about technology, and I took questions from them. One of them asked: “If we are going to be obsolete because of robots, then why did our parents have us? And why are we here?”. This is just something that I have never heard before, and when the question was asked there was this kind of agreement in the room. So, if their starting point is one of despair, then it is going to be hard for them to be able to imagine change, to be able to imagine something that is better.

Humanity has been through so many close calls, so many disasters, that I really believe that, based on our past record, we will make it through again and everything will be ok. But I really have to say that it is a fearsome time; it is a scary time.

I am relieved to hear that you remain optimistic, but it seems there are so many huge changes happening at the same time. Do you think that the current education model needs reimagining? What role do you think education should play in preparing the younger generations?

Well, you know, ideally, education should be the core process of a decent society and the core process of a creative civilisation. It is not just “aiding”, it should be the centre of everything, and it should be the central activity of civilization, once people have their basic needs taken care of. However, education, as it exists today, very rarely has that character, and there are many examples I could give you. It is still almost universally the case that, if you take a technical degree in engineering or information science, you are not required to take an

Below:
Jaron Lanier, photographed in 1990, surrounded by demonstration images of the virtual, non-real worlds that VPL had created.



When we teach something like literature, we believe that we should also teach critical thinking, but when we teach something like technology, we believe that we should only be teaching skills, and that is a false distinction. If anything, critical thinking is more important for technology.

ethics class. Now this is beginning to change. There are some programmes that have that requirement, but it is just remarkable to me that you can get a PhD in computer science in most places without ever having been challenged to think about what is actually going on in the world, or what the world needs—that is just astonishing and appalling. There is just still a very long way to go to get to the point where education is serving our needs well.

I would like to add a particular comment as well about primary education. There is currently a big drive all over the world to teach children computer programming, and what is meant by this is how to do 1950s-style elementary programming. Now there is nothing wrong with that, it probably teaches a little bit of thinking skills and discipline and that is all fine. However, the kind of programming that is having an impact in the world today is completely unlike the kind that you learn about in these courses. The world today is being run by machine learning algorithms and they are treated as “black boxes” that a special few can understand. Currently, there is only a tiny handful of projects trying to teach kids about this kind of programming. I am involved in this initiative, I am trying to improve that situation, but, in most cases, the type of education that can help people prepare for their world and understand their world is completely absent.

Do you think that education systems should instead focus on nurturing and teaching a set of “master competences” that then can be applied across different contexts and unforeseen scenarios?

Yes. When we teach something like literature, we believe that we should also teach critical thinking; but when we teach something like technology, we believe that we should only be teaching skills, and that is a false distinction. If anything, critical thinking is more important for technology. So, yes, I am happy for kids to be learning skills, although in reality it will only be a small minority that will have an opportunity to apply these skills in a job running a deep learning system somewhere in the future. What I would really like kids to learn today is critical thinking regarding technology; that is the key missing link that just has to be taught.

*This interview has been edited for length and clarity.

NEUROSCIENCE & LEARNING



THE INTERFACE OF TECH

Neuroscientific knowledge on human learning and emerging technologies remains an under-used lever in efforts to resolve the global learning crisis. We need to accelerate the dialogue to address this crisis with renewed determination and decisiveness.



In these times of amazing technological advances, it seems especially important to reflect on how emerging technologies can impact education and learning. It is even more necessary to ask ourselves how we can use these technologies and new areas of knowledge to fulfill our goals for quality, universal, and inclusive education and learning, leading to a more just and open society.

Tabaré Vázquez
President of Uruguay

FOR THE
FUTURE
OF
EDUCATION
TECHNOLOGY
MATTERS

Self-directed learning often demands that the learner interpret conflicting information, seek clarification, and make informed decisions about personal dilemmas. How can technology help students develop the knowledge and skills to self-direct their learning throughout life?

by

by Marcia C. Linn, Elizabeth McBride,
Libby Gerard, Adi Kidron

Preparing people to be effective lifelong learners is a significant challenge of the twenty-first century, characterized, as it is, by constant and rapid change. The level and pace of change can render specific insights and skills obsolete, challenging people to repeatedly refine their knowledge in new scenarios and with new tools. Adaptation to new contexts necessitates sustained lifelong learning. Yet, many education systems struggle to enable students to become effective lifelong learners (Marope, Griffin, and Gallagher, 2017).

Guiding students to become self-directed lifelong learners is often overlooked in education, where the emphasis instead focuses on covering all of the information that experts think students need to learn. Yet, what is learned at school or college can easily become outdated. Preparing students to respond and adapt their knowledge to new information is essential in the fast-changing twenty-first century context (Marope, Griffin, and Gallagher, 2017). Rather than learning by rote, students need opportunities to test and refine their ideas. Even when students conduct hands-on investigations, curricular materials may emphasize following directions rather than using evidence to inform their own decisions. Instead of following instructions or memorizing information, students need to generate conjectures and formulate methods to test their ideas. Emerging technologies remain an under-utilized resource in self-directed learning.



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Fostering self-directed learning through science

Science courses illustrate how teachers can use technology to foster and reinforce effective self-directed lifelong learning. Scientists are frequently required to resolve conflicts between different findings, and science courses that emulate this practice are ideal for building capacity for self-directed learning. This good practice can inform the transformation of courses in most disciplines, fostering self-directed lifelong learning as a core, global, future competence (Marope, Griffin, and Gallagher, 2017).

Self-directed science students test their ideas by seeking new information and by revising their ideas based on that information. Because the internet makes both valid and invalid information readily available to users, it is more important than ever to teach students to investigate the ideas they encounter and assess whether they are credible and relevant to the task at hand.

To engage students and facilitate self-directed learning, instruction featuring interactive models and simulations can bring real-world dilemmas to life in the science classroom. Two examples, developed in the Web-based Inquiry Science Environment (WISE: <http://WISE.Berkeley.edu>), illustrate this

opportunity. First, students explore how different treatment options for cancer can disrupt mitosis. Second, students design a solar oven to gain insight into how solar energy can contribute to energy-efficient home heating. Helping students engage in self-directed learning using technology entails multiple challenges. To meet these, WISE has been tested and improved by over 20,000 teachers and their students in Europe, Asia, Australia, Africa, North America, and South America.

In the WISE mitosis unit, students are guided to explore how fictitious plant-based drugs disrupt mitosis to treat cancer (Gerard, Ryoo, McElhaney, Liu, Rafferty, and Linn, 2015). Students use an interactive model to test how the drugs affect mitosis, and then interpret graphs showing how well they treat cancer. At first, when students use this unit, they are unsure how to proceed. When asked what aspect of mitosis a cancer drug should target, many responded, “I don’t know”. Others gave vague answers.

In the solar ovens unit, students design, build, and test their own solar oven, guided by WISE activities. Rather than planning their designs using the relevant science principles, students often rush

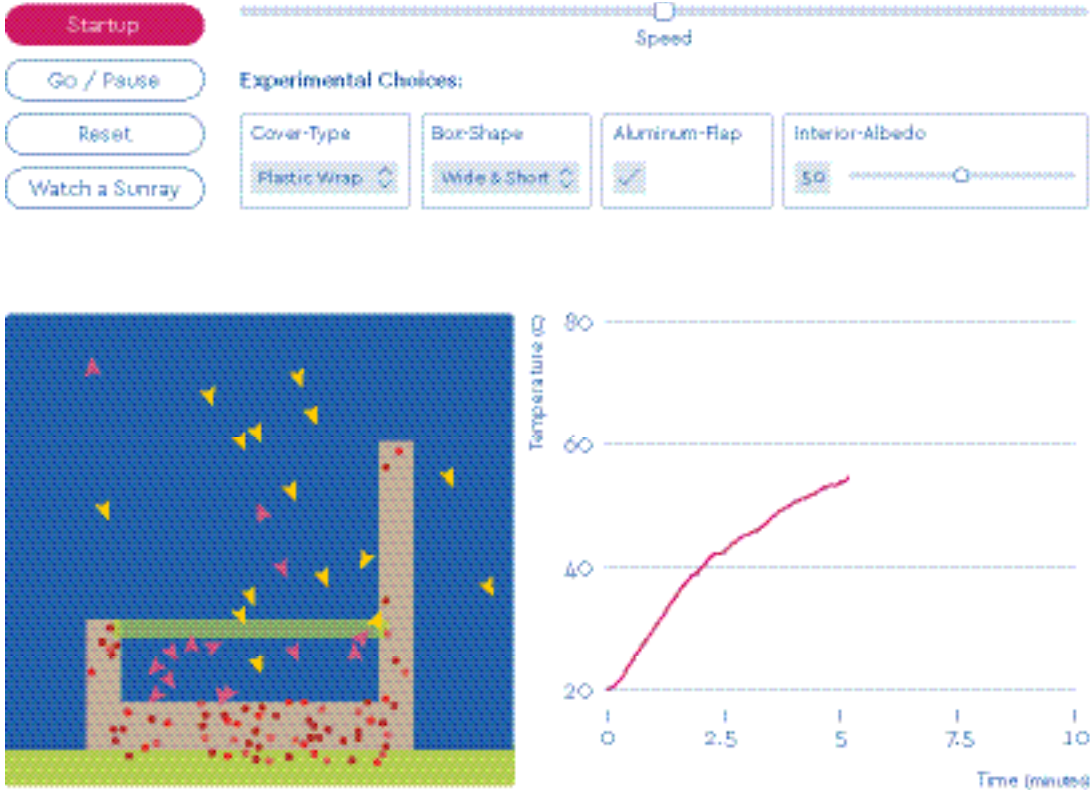
to create their ovens. When they rush through the design process, they tend to make decisions based on intuition rather than scientific evidence. For example, many students cover the opening of the oven with aluminum foil instead of clear plastic because they think metals attract energy.

To emulate the scientific method, the pedagogical processes implemented in WISE have been designed to motivate students to revise their initial essays and designs after discovering new evidence. This worked for some students in the two units. However, many students did not revise their essays or designs, or made only superficial changes (e.g., adding a word, improving punctuation, taping a small hole in a solar oven). To optimize the role of teachers and technology to guide students’ essay (Gerard, Ryoo, McElhaney, Liu, Rafferty, and Linn, 2015) and design (McBride, Vitale, Applebaum, and Linn, 2016) revisions, insights are drawn from knowledge integration (Linn and Eylon, 2011). Knowledge integration guidance for revision encourages students to discover new ideas and modify their initial essay or design to fill gaps, resolve inconsistencies with evidence, and strengthen connections.

Combining teachers and technology to promote self-directed learning

Teachers reinforce technology in guiding students to become self-directed learners. Teaching and technology can promote self-directed learning in a symbiotic relationship that values the diverse array of ideas which learners acquire from their collective experiences (both inside and outside of the classroom). Extensive evidence suggests that learners grapple with multiple, conflicting and often confusing ideas about scientific phenomena. For example, students designing solar ovens may argue that metal attracts heat while also arguing that metals reflect the sun. Teachers and technology can elicit these ideas, so they can be used as productive starting points for students to test and revise their ideas, and to develop lifelong learning competence. For example, prompting students to articulate their existing ideas by making predictions or brainstorming ensures that these initial ideas are examined and refined as students learn new ideas.

WISE activities featuring experiments, models or simulations can strengthen this process by enabling students to add new scientific ideas. Technology can help students build a repertoire of ideas by offering carefully designed activities. Using a solar oven model (see Figure 1), for



#	Box Shape	Cover Type	Flap?	Int Albedo	Temp at 0m	Temp at 1m	Temp at 5m	Temp at 10m
1	Wide and Short	Plexiglass	Yes	50	20	30.4	59.7	65.8
2	Skinny and Tall	Aluminum Foll	Yes	50	20	24.7	33.9	43.8
3	Skinny and Tall	Plexiglass	Yes	50	20	26.7	43.5	48.2

Figure 1:
Students use this model
to test their ideas about
how to design a solar oven.

example, students can compare the effect of lining their oven with foil or black paper and add ideas about whether materials reflect or absorb light energy.

Teachers can facilitate this process by guiding students to extract new insights from their interactions with the technology. By helping their students to develop coherent ways to evaluate the scientific ideas they encounter and compare these with their own initial ideas, teachers can reward self-directed learning. And, by comparing alternative designs, students can distinguish between their own ideas and new ones.

WISE activities encourage students to write essays in order to reflect on the evidence and to revisit their own initial ideas to consolidate their experiences. Teachers and the technology can guide students to analyse their repertoire of ideas and to iteratively revise their essays.

Students gain practice in self-directed learning by articulating their own ideas; building a repertoire that combines their own ideas and ideas from simulations, experiments or models; distinguishing among the ideas in the repertoire; and reflecting on the resulting insights. Guiding stu-

dents to use these four learning processes in combination promotes coherent understanding and enables lifelong learning. These processes are based on studies of how students think about, refine, compare, and integrate their diverse repertoire of ideas (Linn and Eylon 2011). This process of eliciting ideas, discovering new ideas using evidence from experiments, models, or simulations, distinguishing among the ideas, and reflecting on the results enables students to integrate their ideas rather than continuing to accumulate disconnected or disjointed ideas. Students can revise and reformulate their views as they encounter new evidence throughout life.

Teaching and technology can promote self-directed learning in a symbiotic relationship that values the diverse array of ideas which learners acquire from their collective experiences (both inside and outside of the classroom).



Instruction featuring interactive models and simulations can bring real-world dilemmas to life in the science classroom. Personalized guidance demonstrates respect for each student’s ideas about a science topic and promotes refinement over memorization.

Evaluating and revising ideas for self-directed learning

In both the mitosis and solar oven examples, students experienced challenges in switching from textbook or teacher-directed learning to self-directed learning. Many students were initially unsure about how to revise their essays or designs or how to use virtual models to test their understanding of a topic. Teachers can guide students to revise their essays by building on the evidence they collect. For example, in the mitosis unit, students were asked to use a model to explain how mitosis gets out of control. They explored the role of the cell wall in mitosis and cancer treatment. Teachers promoted self-directed learning by evaluating student essays using a rubric that rewards knowledge integration. The teachers guided students to improve their essays by helping them locate relevant evidence and use it to critique their response (see essay, scoring rubric, and guidance in Table 1). Guidance on how to use evidence to strengthen their response helped students to integrate their ideas (Gerard, Ryoo, McElhaney, Liu, Rafferty, and Linn, 2015).

Analysis of audio recordings from teacher–student interactions highlighted ways in which teachers use the computer-generated knowledge integration guidance as a starting point to strengthen stu-

dents’ revisions of their ideas (see Figure 2).

Effective uses of technology to log student actions supported teachers in guiding revision. For example, teachers appreciated alerts that used logged data to show which students responded with vague ideas when asked which plant is a candidate for a cancer drug. This helped teachers to identify in real time which students needed additional teacher support and which could continue to investigate on their own. In addition, algorithms were used to analyse how each student revised in response to computer and/or teacher guidance. This helped teachers to reflect on the impact of the guidance and refine their own approach.

Furthermore, teachers can use WISE technologies, such as interactive virtual models, to help students develop and answer their own questions. Teachers can guide students to revisit the model instead of telling them the right answer. Thus, teachers can use guidance to help students practice self-directed learning.

In one study, the teacher’s personalization of the computer guidance significantly increased the number of students who re-

vised (96% of the students in the class) and the quality of their revisions compared to when they used the computer guidance alone (Gerard, Ryoo, McElhaney, Liu, Rafferty, and Linn, 2015). For students who needed evidence, the teacher prompted them to consider a new idea and directed them to the model. For students who needed to distinguish between the ideas in their explanation, the teacher asked them to elaborate and add details. By personalizing guidance for revision, the teacher helped all students to develop strategies to revise their ideas. She also fostered a process of self-directed learning by asking questions rather than telling answers.

Students in the WISE solar ovens unit could interact with a virtual model of a solar oven to connect their design-and-redesign process with science principles (Figure 1). This model made some of the mechanisms behind effective solar ovens visible. For example, it showed how solar radiation from the sun is transformed into heat energy. Using the virtual model, students could compare an oven covered with foil to other oven designs, in order to revise their original design (McBride, Vitale, Applebaum, and Linn, 2016).

A classroom study compared how well students learned when they used the model to plan or to redesign (McBride, Vitale, Applebaum, and Linn, 2016). In the planning condition, students used the virtual model to generate alternative ideas and test them. In the redesign condition, students used the virtual model to test possible revisions to their physical model. Students were randomly assigned to the planning condition or to the redesign condition. Students in the planning condition became proficient at directing their own experimentation. They tested ideas and connected their tests to the underlying science principles. In contrast, the redesign condition primarily motivated students to use the virtual model to test the oven they had just designed.

QUESTION			
Remember that cancer is mitosis out of control. Why or why not would you recommend this plant as a medicine for cancer?			
To score student essays, graders look for integration of these key ideas in student responses:			
1) cell structure or cell phase affected by plant; 2) how plant affects the cell structure of cell phase; 3) plant effect on cancer; 4) side effects of plant on the whole body.			
SCORE	KNOWLEDGE INTEGRATION LEVEL	EXAMPLES	KNOWLEDGE INTEGRATION GUIDANCE. EXAMPLE OF TEACHER-PROVIDED OR AUTOMATED GUIDANCE
1 Off-task	Irrelevant	IDK	Look for more ideas using the unit. Test the plants using Steps 1.3 and 5.1
2 Incorrect ideas or link	At least 1 alternative idea stated. Repeats question.	Affects the cell wall. Cancer is mitosis out of control. Would not work.	What happens to the cell treated by Plant B? Why does this matter for curing cancer? Reconsider the evidence in Steps 5.1 (Plant B) and 1.3 (cancer). Then, rewrite your recommendation.
3 Partial link	Mentions only one of the four types of key ideas.	Yes, it stops the spindle fibers from stretching. Yes, because it stops metaphase.	You described how Plant B affected cell division. How did Plant B do this? Why does this matter for curing cancer? Reconsider the evidence in Steps 5.1 (Plant B) and 1.3 (cancer). Then, elaborate your recommendation.
4 Full link	Two of the four types of key ideas are connected meaningfully.	Yes, because it interferes with metaphase that will prevent the cell from dividing.	Good analysis of the effects of Plant B on cell division. Why does this matter for curing cancer? What are possible side effects (on the whole body) of stopping mitosis to treat cancer? Elaborate your recommendation.
5 Multiple links	Three of the four types of key ideas are connected meaningfully.	Yes, it interferes with metaphase which will prevent the cell from dividing in 2, stopping the spread of cancer through the body.	Good analysis of the effects of Plant B on the process. What are possible side effects (on the whole body) of stopping mitosis to treat cancer? Elaborate your recommendation.

Conclusions

In the effort to ensure that students acquire all the disciplinary knowledge and practices deemed essential for dealing with contemporary problems, their preparation to become lifelong learners is often overlooked. By combining the knowledge-integration pedagogical framework with powerful technologies and teacher guidance, students can be set on a path to become effective self-directed lifelong learners. Bringing teachers and technology together can give students a firm foundation for developing a coherent understanding of new topics they encounter in life by drawing on evidence from multiple sources. WISE has potential to guide teacher professional development programmes in how to use students’ work to refine instruction, enabling teachers to self-direct their learning about students’ ideas and pedagogical choices.

This article is based on work supported by the National Science Foundation under grant numbers 1451604 and DRL-1418423. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.



Human imagination drives exploration, innovation, and discovery. While the physical world—the ocean, stars, fungi, flowers, and bacteria—continues to pique human curiosity on all continents, there is no more fascinating scientific field than the study of the human brain; as far as we know, the most complex organism in the universe.

Technology has advanced our understanding of the learning brain over the past few decades, offering insights that can improve education.

Scientific discoveries have increased rapidly since the 1990s (dubbed the “decade of the brain” in the United States) thanks to huge investments in neuroimaging techniques, which allow a more accurate view of human brains as they perform tasks. For the first time in history, we can study the brains of healthy students in their classrooms as they learn, not just in laboratories under microscopes (Bevilacqua et al., 2019). This gives us better insights into how learning occurs, which, in turn, can help us improve our teaching. The new insights into the learning brain and how teaching influences its processes have already changed some of long-held beliefs about the best ways to educate. This fast learning curve is buttressed by even faster advancements in information and communication technologies (ICTs), particularly the Internet, which eases collaboration and knowledge exchange among researchers in the field, while also broadening access to that knowledge. Though rapid recent advances make this development seem new, in fact it goes back thousands of years.

Historical roots to understanding the learning brain

The Egyptians, Greeks, and Romans gave us the first glimpses into the physiology of the human brain. The first documented studies of the human brain date back to 1700 BC in Egypt, after which Greek natural philosophers speculated about the anatomical seat of cognitive, motor, and sensory functions and the origin of neural diseases (Crivellato and Ribatti, 2007). Alcmaeon (500 BC) was the first to identify the brain as a source of human consciousness, but Roman physicians, such as Galen (129–216 CE), were the first to document their experimental studies showing areas related to motor and sensory processing. In the fourteenth century, the Dutch scientist Jehan Yperman identified three functional areas of the brain, for visual, gustatory and olfactory senses, hearing, and memory. Thus began the search to “localize” brain functions. Where did “reasoning in the brain” occur? Where did “maths in the brain” occur? Why are some people smarter than others?

The first technological advances in the study of the brain related to standardization of practice, predominantly through autopsies and mainly on damaged brains. Magnus Hundt (1449–1519) published anatomical illustrations

depicting the brain in terms of special senses and ventricular systems. Leonardo da Vinci’s (1452–1519) sketches of a centenarian’s brain and Andreas Vesalius’s (1514–1564) anatomical work not only created detailed visual records but also led to consistent naming of specific brain areas, creating common terms of reference and vocabulary. Among the most complete early depictions of the brain were architect Christopher Wren’s engravings for Thomas Willis’ (1664) *Cerebri Anatome* [The Anatomy of the Brain] (Tokuhamma-Espinosa, 2010).

The Medieval Age in western Europe coincided with the Islamic Renaissance (7th–13th centuries), when Middle Eastern thinkers contributed to great historical advancements about human learning and physiology (Clarke, Dewhurst, and Aminoff, 1996). In Persia, prominent scholars such as Avicenna, Rhazes, and Jorjani established medical practice based on observational data using the premier technology of the day: the trained eye. Ali ibn Abbas Majusi Ahvazi was a renowned Persian scientist of this era who wrote a large medical encyclopaedia entitled “*The Perfect Book of the Art of Medicine*”. It comprised 20 chapters, each of



Above: Christopher Wren’s engravings for Thomas Willis’ *Cerebri Anatome* (1664). The brain stem with nerves and vessels, including the circle of Willis, is depicted by Wren in a similar fashion to an architectural drawing.

Towards a scientific study of the learning brain

which began with an anatomical discussion and not only included information on diseases and treatments, but also offered detailed descriptions, including of cranial nerves and sutures, inching humankind closer to a better understanding of the complexities of the human brain.

Al-Haytham (Latinized as Alhazen), (965–1039), was an Arab mathematician, psychologist, and physicist of the Islamic Golden Age. Biographers call him the “inventor of the scientific method”. He established that learning is generated by our sensory perceptions of the world, confirming Aristotle’s original idea from 800 years earlier. In this process, our senses feed information to our memory, and we compare new with old, detect patterns and novelty, and base new learning on past associations. While the neural mechanisms for memory were not completely understood at the time, this work laid the foundations for our understanding of memory systems, which were later acknowledged as one of two vital foundations of all learning, the other being attention. Without both well-functioning memory and attention systems, there can be no learning (Tokuhamas-Espinosa, 2017).

It wasn’t until the seventeenth century, however, that the invention of the microscope and the discovery of bioelectricity showed how the brain works through electrical and chemical exchanges. In 1754, Johann Gottlob Kruger suggested the use of electro-convulsive therapy for mental illness, indicating an un-

derstanding of how human behaviour was controlled by electrical and chemical changes and contact with the environment. These insights into the brain showed that electricity could change the chemistry of the brain, opening the way to a new field of molecular biology, which was then able to establish that new learning could be measured through increases in “white matter” when new connections are made in the brain.

The final decades of eighteenth century witnessed a growth of interest in the localization of brain functions, but not always based on technological discoveries. In 1792, Franz Joseph Gall and J. G. Spurzheim advocated the idea that different brain regions were responsible for different behavioural and intellectual functions, producing bumps and indentations on the skull. They thought that the more highly developed areas would require more volume of the cortex and the part of the skull covering this area would bulge outward and create a “bump” on the person’s head (Fancher, 1979). Phrenology used no technological tools and was based on an individual’s interpretation on feeling a person’s head shape. Phrenology has since been discredited, but it did teach a key

A better understanding of the mind led to increased curiosity about the brain, the physical organ behind learning. Speculation occurred as to the underlying factors contributing to the learning difficulties some children faced. Using the factory as a metaphor in which one material went in and another came out, more and more people wondered just how the “black box” of learning actually worked.

lesson in the learning sciences: simplistic answers are rarely the whole truth when it comes to the brain. Human personality and thought processes are far more complex than once believed. This ushered in an era of acceptance, and even celebration, of the complicated neural networks that underlie cognition.

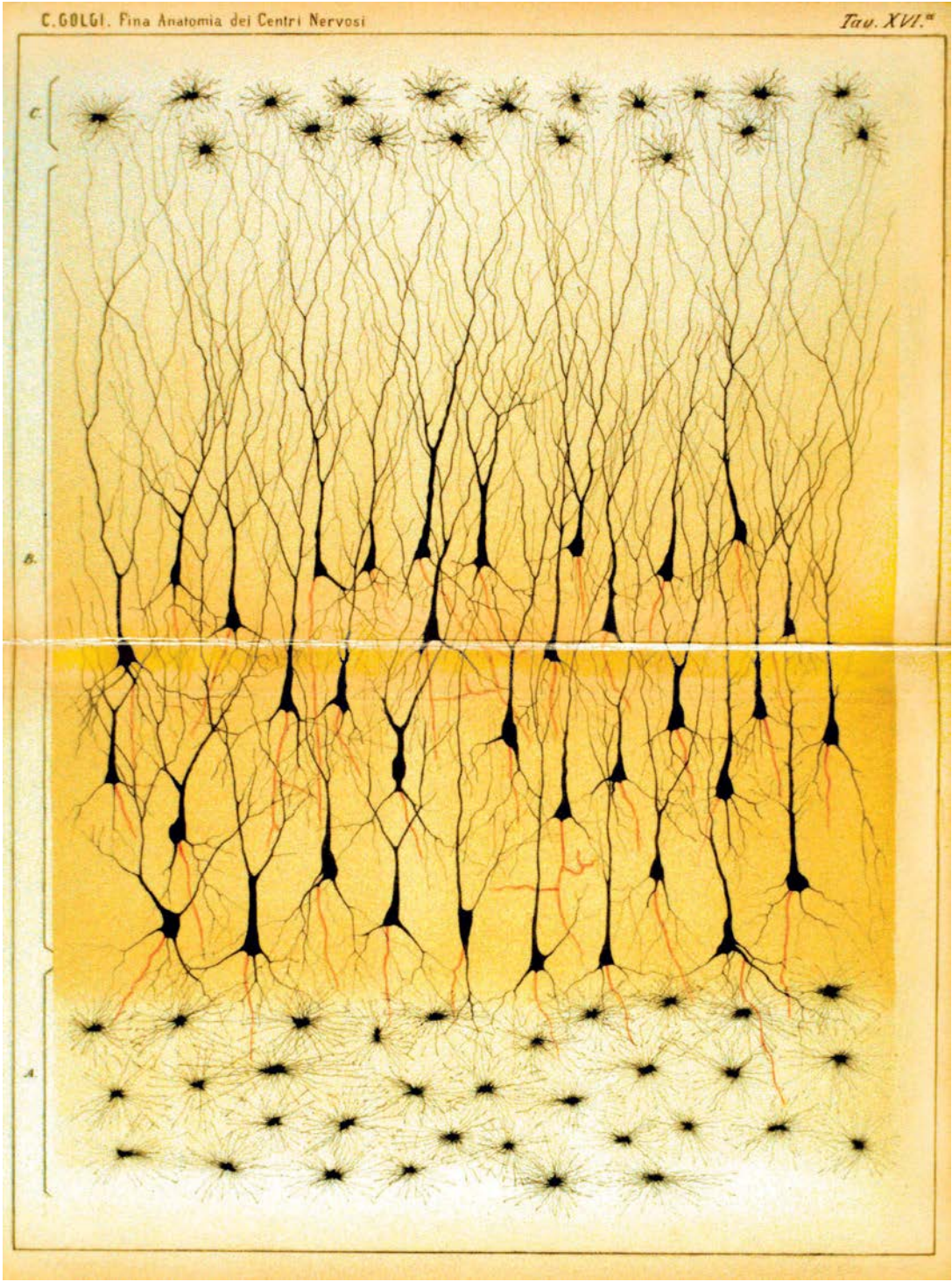
Many simplistic explanations of the brain that followed were motivated by profit-making schemes of “brain-based teaching” products. People paid large sums of money to learn about pre-determined “learning styles” (a neuromyth), to distinguish between right- or left-brained thinkers (a neuromyth), and even how to teach to the differences in boys’ and girls’ brains (a neuromyth) (Dekker, Lee, Howard-Jones, and Jolles, 2012).

By the Industrial Revolution, human observation, dissection, and interventions became more commonplace and the new field of psychology began contributing to knowledge about how people learn (David Hartley published *Observations of Man* in 1749, the first English work using the word “psychology”). A better understanding of the mind led to increased curiosity about the brain, the physical organ behind learn-

ing. Speculation occurred as to the underlying factors contributing to the learning difficulties some children faced. Using the factory as a metaphor, in which one material went in and another came out, more and more people wondered just how the “black box” of learning actually worked.



Above: French phrenological chart, 19th century.



Above:
Part of a vertical section through the human pes hippocampi majoris.

Source:
Camillo Golgi (1885), *Sulla fina anatomia degli organi centrali del sistema nervoso* [On the fine anatomy of the central organs of the nervous system], Reggio-Emilia: S. Calderini e Figlio. Public domain.

Seeing the invisible

During the Industrial Revolution, people began to think more about the role of neurons—cells in the nervous system—in the learning process. Cell theory states that the cell is the basic structure in all living organisms, including humans. This idea was suggested more than 100 years earlier by Robert Hooke in 1665 but was rejected due to lack of proof at the time. A contemporary of Hooke’s, Anton van Leeuwenhoek, advanced the concept of cell biology by proving that cells were living organisms. It wasn’t, however, until the 1830s that German scholars Jakob Schleiden (1838) and Theodor Schwann (1838) discovered individual units in plant and animal bodies, which they called “cells”. Although cell theory quickly became universally accepted after 1839, most scientists of the nineteenth century, limited by the technology of the times and unable to see most cells with the naked eye, believed that the nervous system was a continuous reticulum of fibres, not a system of cellular networks. This is yet another example of how wonderful ideas in science are often discovered before technology catches up to confirm them.

Another advance that made the fundamental building blocks of learning observable occurred in

Although cell theory quickly became universally accepted after 1839, most scientists of the nineteenth century, limited by the technology of the time and unable to see most cells with the naked eye, believed that the nervous system was a continuous reticulum of fibres, not a system of cellular networks.

1873, when an Italian scientist, Camillo Golgi, developed a staining process that made neurons and their connections easier to study under a microscope. Thanks to this, in 1886 Wilhelm His and August Forel proposed that the neuron and its connections might be an independent unit within the nervous system (Evans-Martin, 2010).

A few years later, in 1888, Santiago Ramón y Cajal discovered the presence of strictly organized neuronal circuits as a fundamental characteristic of all brains (Llinás, 2003). However, it was not until after the invention of the electron microscope in the early 1930s that evidence showed definitively that neurons could communicate with each other (Evans-Martin, 2010).

By the end of the nineteenth century, Francis Galton’s studies provided the basis for a statistical approach to measuring mental abilities, including intelligence. Galton, one of the first British psychometricians, was enamoured with the “normal distribution” and its success in describing many physical phenomena, which persuaded him that it would permeate all manner of other measurements and in particular mental measurements (Goldstein,

2012). Following Galton’s work, researchers such as Alfred Binet (Binet and Simon, 1904) and David Wechsler (Wechsler, 1939) developed instruments to measure mental abilities, which were later formed the first intelligence tests.

Discoveries related to cortical function continued in the early twentieth century. In 1908, Korbinian Brodmann drew a cortical map of the brain based on comparative studies of mammalian cortex. He identified 52 cortical areas known today as Brodmann’s Areas. The advancement of new technologies in the early 1900s assisted researchers in understanding the neural activity in the human brain.

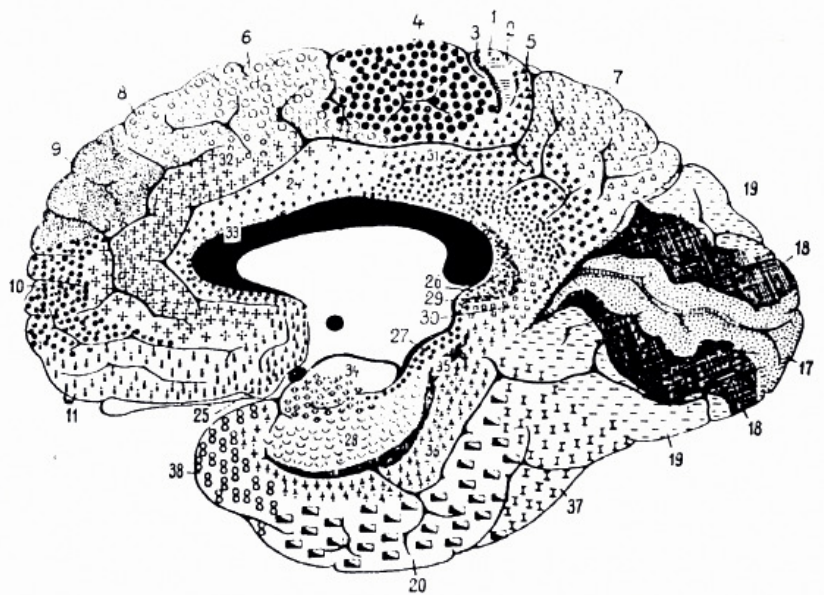
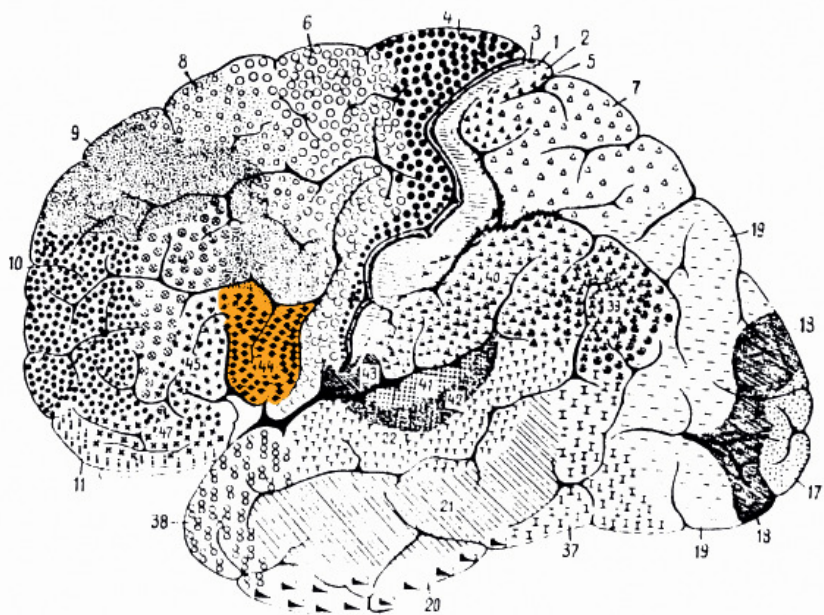
In 1929, Hans Berger recorded the electrical activity of neurons using electrodes placed on the scalp and called the record of the signals an “electroencephalogram” (EEG) (Haas, 2003). Six years later, in 1935, Edgar Douglas Adrian verified that this information is transferred between neurons via trains of electrical activity, which vary in frequency based on the intensity of the stimulus. This laid the foundation for the future discovery of electrical synapses, hypothesized by Golgi and Ramón y Cajal in 1909, well before their existence was confirmed in the

1950s (Kandel, Schwartz, and Jessell, 2000).

The early 1900s also produced valuable new understandings about the connection between the physical structures of the brain and psychological processes of learning and memory. Karl Lashley proposed the theory of equipotentiality, namely the ability of any neuron to do the job of any other (Lashley, 1930), which was in stark contrast to the views of the localizationists of the time, who thought that each brain area specialized in a particular function. Today, it is accepted that both were partially right, but neither was entirely correct.

Investigation of the neurobiological bases of learning was begun in earnest by Donald Hebb in the first half of 1900s. Hebb’s now famous saying that “neurons that fire together wire together” (Hebb, 1949), challenged both Lashley and the localizationists. Hebb was one of the first to suggest that neurons generally connect to their closer neighbours, which introduced a new vision of neuronal networks, as opposed to simple individual cell activity. This was only shown to be true in 2009 by the Connectome Project (Sporn, 2012). This concept had valuable implications for

classroom learning as it offered a neurophysiological explanation of why certain types of memories seemed to cluster together in recall activities.



Above:
Brodmann area 44.

Source:
Cytoarchitectonics, adapted
from Brodmann (1908).
Public domain.

The emergence of science in understanding the learning brain

The early twentieth century saw new hypotheses about human learning drawn from animal research. Ivan Pavlov’s studies on conditioned reflexes in dogs laid the foundation for the application of conditioning techniques in behaviour modification in classrooms. Pavlov’s work provided John Watson with a method for studying behaviour and a way to theorize how to control and modify it (Schultz and Schultz, 2011). In 1913, Watson introduced the term behaviourism and served as the most vocal advocate for the behaviourist perspective in the early part of the century (Watson, 1913).

In 1958, Mark R. Rosenzweig and his colleagues at the University of California, Berkeley published the results of experiments on rats that opened a new line of investigation related to the neurobiological basis for behaviour and the influence of “enriched” environments (Krech, Rosenzweig, and Bennett, 1958). This gave birth to a new business of “early stimulation classes” for children, in which babies were taught to recognize shapes on flash cards. These earlier works were mistakenly seen by the public as supporting early stimulation classes for infants, when they were really a condemnation of poor

or deprived environments. Six years later, Marian Diamond and her colleagues, also at Berkeley, published a study which showed that exposure to “enriched” experiences changed the dendritic arborization and functional connectivity of brain cell networks in rats (Diamond, Krech, and Rosenzweig, 1964). Building on Diamond’s work, William Greenough explored the plasticity of brain or brain capacity to change with experience.

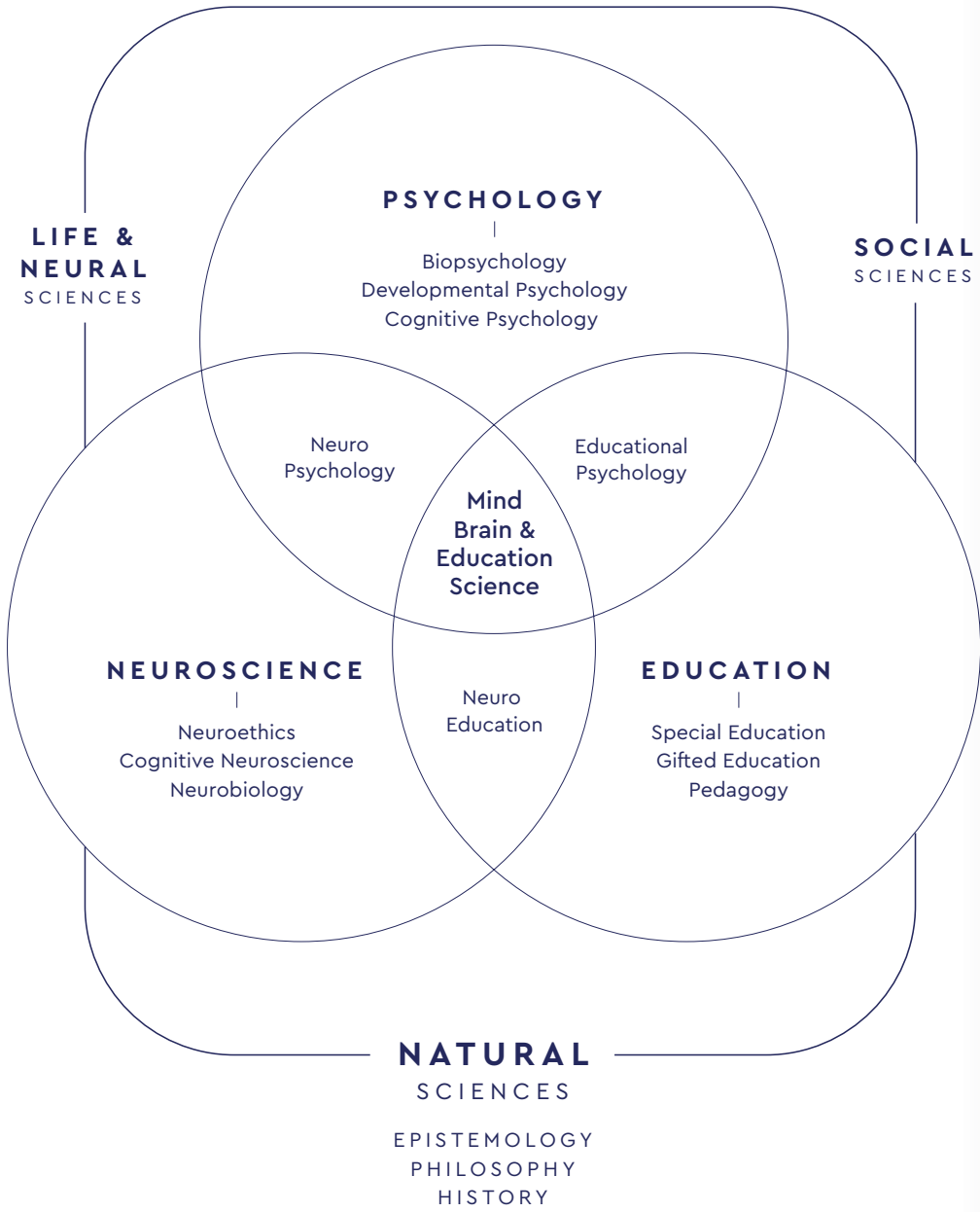
Science and technology interface to advance the understanding of the learning brain

As interest in the brain grew among the public, the United States declared the 1990s the Decade of the Brain. This announcement was accompanied by new funding and investment in the learning sciences as a whole, and in technology in particular. The advancement of new brain-imaging techniques (including refined functional magnetic resonance imaging [fMRI]) profoundly influenced scholars to think about the practical applications of brain research for educational policy and practice. More than 32,000 peer-reviewed articles published between 1990 and 2000 used MRI or fMRI scans to measure some element of learning. However, not all of these studies focused on human learning. In fact, only a handful of studies during this time used human subjects, and even fewer were conducted on school-aged children. The lack of evidence directly gathered from school-aged children, along with the promotion of neuro-myths, prompted caution about the true utility of neuroscience research and teaching.

Neuroimaging: A critical technological breakthrough

Advancements in neuroimaging techniques from 1990 to the present, in terms of both measurement accuracy and data analysis, marked key milestones in the development of the learning sciences, especially Mind, Brain, and Education (MBE) science. Technology began to link observable learning in classrooms to molecular-level changes in brains in laboratories to better understand how the teaching-learning dynamic actually works.

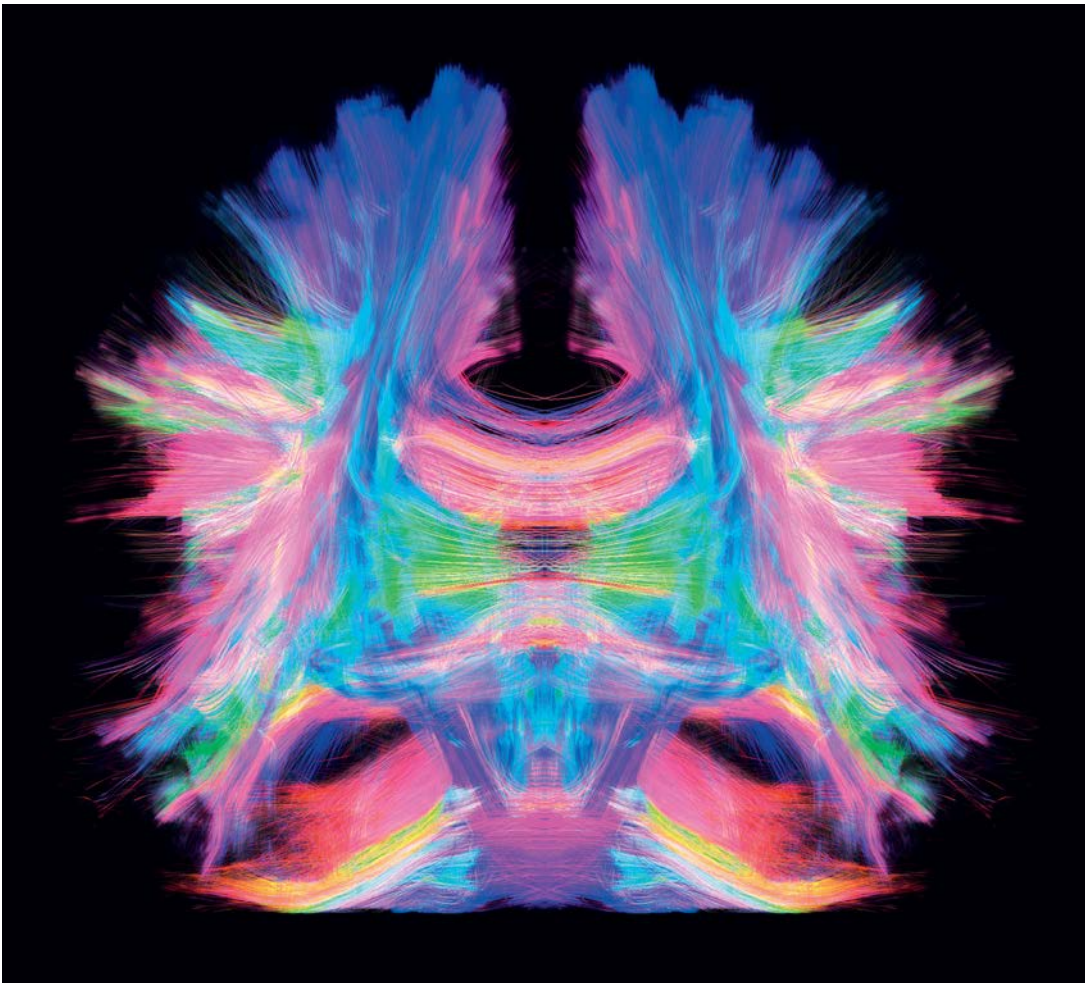
The Human Connectome Project (HCP), a US National Institutes of Health initiative launched in 2009 to “construct a map of the complete structural and functional neural connections in vivo within and across individual” (Bookheimer et al., 2019), not only financed important international studies but also gave the general public a new view of the complexity of human thinking through publicly available images. The project includes researchers from dozens of institutions, including Washington University, University of Minnesota, Harvard University, University of California at Los Angeles, University of California Berkeley, St. Louis University, Indiana University, D’Annunzio University, University of Warwick, University of Oxford, and the Ernst Strüngmann



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Institute. The HCP undertook a systematic effort to map macroscopic human brain circuits and their relationship to behaviour in a large population of healthy humans (Van Essen, 2013).

By combining existing neuroimaging tools, the HCP created colourful, detailed neural circuitry maps that told the visual story of reading problems, how arithmetic is processed in healthy brains, and mapped hundreds of other cognitive skills and sub-skills that were previously invisible to the naked eye. The findings were made popular among the general public by Sebastian Seung in his book, *Connectome: How the Brain’s Wiring Makes Us Who We Are* (Seung, 2012).



Above:
Axonal nerve fibers
in the real brain.

Practical interventions based on neuroscience for the classroom

Thanks to the Connectome, the learning sciences extended beyond the theoretical and turned practical.

Learning technology in multiple forms, including apps, video gaming and augmented reality, as well as platforms that offered teachers services to improve student learning, began to increase exponentially in the twenty-first century, creating by 2018 an industry worth \$6 billion, out of the total of \$21 billion spent on computers, video and gaming (Entertainment Software Association, 2018). Several manufacturers claimed to work with cognitive neuroscientists to create unique instructional designs in educational programming, but only a handful of studies supported these claims.

Nonetheless, the potential for marrying the benefits of technology and neuroscience became clear in the second decade of the twenty-first century. An OECD (2017) report suggested that two areas of necessary growth for teacher education included technology and neuroscience. Combining technology with the learning sciences poses an interesting challenge and has generated multiple research studies.

Perhaps the most important advances in the second decade of the current century have been in research. Initial studies have directly gathered neuroscientific data from real-live classrooms, with real children, using both psychological and observational methods, as well as molecular/neuroscientific tools. Studies by researchers at the Queensland Brain Institute, for example, research multiple aspects of learning, such as “Brain-to-Brain Synchrony and Learning Outcomes [that] Vary by Student-Teacher Dynamics: Evidence from a Real-world Classroom Electroencephalograph” (Bevilacqua, 2018).

Such ground-breaking research appears to explicitly show the benefits of combining neuroscientific research with psycho-social interactions in real classrooms, paving the way for a new kind of teacher training based on evidence about the brain and teaching.



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The next generation of scholars is challenged by the same goals as the ancient sages; make the invisible visible. In doing so, they must enlighten the public about the ethical use of credible neuroscientific knowledge to advance human learning, and ensure equity of effective lifelong learning opportunities.



Where are we headed now?

Non-invasive neuroimaging techniques have proven an invaluable tool for understanding brain development and functional reorganization in typical and atypical child populations, from infancy through adolescence (Dick et al., 2013). Just as the first microscopes in the 1800s gave way to electron microscopes in the 1930s, and Golgi’s stains gave way to Connectome imagery, the future promises an even clearer vision of the brain. Emerging technologies can make unique contributions to answering longstanding educational questions that are not amenable to traditional research methods in psychology and education, and help tailor pedagogical curricula towards pupils’ individual neurocognitive abilities (Fischer et al., 2010; Howard-Jones, 2007). There is no question that technology will make considerable contributions to uncovering the mechanisms underlying neural and cognitive development (Dick et al., 2013).

At the opening of the third decade of the new millenium, we are cautiously optimistic. Technology continues to advance, most notably in areas of neuroimaging where tools are becoming less expensive, more accurate and more widely available. While there is no such thing as a machine that

can read our minds, there are tools to facilitate better learning, using algorithmic patterns which permit students to rehearse basic cognitive skills. Improvements in communication technologies are also bridging communities and advancing the global knowledge base on how the brain learns.

The next generation of scholars is challenged by the same goals as the ancient sages; to to make the invisible visible. In doing so, they must enlighten the public about the ethical use of credible neuroscientific knowledge to advance human learning and ensure equity of effective lifelong learning opportunities.



THE
FRONTIER
OF
NEUROSCIENCE
OF EDUCATION
AND LEARNING

Cutting-edge technology, as well as new materials and techniques, improve our understanding of the learning brain. This new knowledge has an enormous potential to transform the future of education and learning.



I'm very proud of our advancements and competence in science. I'm very proud of our technological capacities, but I am also very concerned about the responsible delivery of technology. I'm in favor of science without borders and technology without borders. I'm in favor of the universal application of the benefits of science and technology.

Michael D. Higgins
President of Ireland



Realizing
the potential
of
neuroscience
and
technology
to
TRANSFORM
education

Just as the burgeoning understanding of biology in the nineteenth century transformed medicine, our new understanding of how the brain learns is set to transform education in the twenty-first century. Much educational thinking still lacks a convincing theoretical basis and studies have shown that misunderstandings about learning are frequent among teachers across the world. These include misconceptions about the brain—so-called “neuromyths”. However, as was the case with medicine, science is beginning to shine a light into the darkness, and help provide a progressive, research-informed basis for the decisions we make in education policy and practice.



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Opening image:
Kumi Yamashita
Title: "0 to 9"
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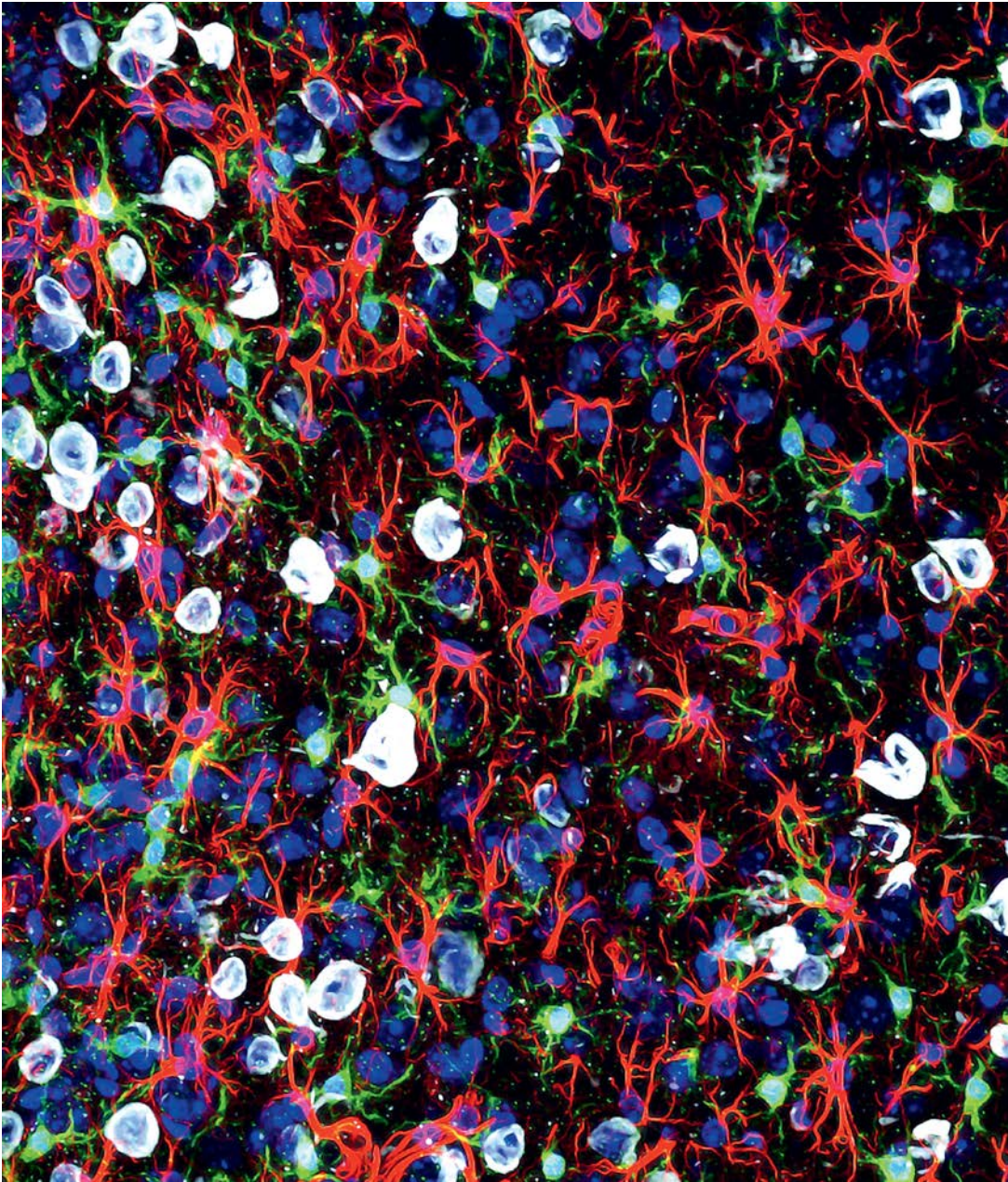
Looking inside
the living,
learning brain

Mutually supportive developments in technology and neuroscience research are producing rapid advances in our understanding of the learning brain. Until the 1990s, most of what we understood about the brain was derived from animal studies and the effects of injury on humans. For example, in the nineteenth century, the French physician and anthropologist Paul Broca discovered a speech production centre in the left frontal region of the brain (now called Broca’s area) after observing that a patient with damage in this region had difficulty in articulating speech, despite being able to understand language normally.

Discoveries such as Broca’s played a significant role in the development of neuroscience. However, it is obvious that the observational methods used were unable to map the complex brain processes by which healthy adults and children learn, or to enhance our understanding of how different interventions can enhance this learning. The development of in vivo neuroimaging made the non-invasive observation of the living human brain possible. This has dramatically accelerated scientific progress in understanding how the brain functions—including how we learn. Using technologies

such as functional Magnetic Resonance Imaging (fMRI), we can now show how different regions of the brain activate and connect when we learn. This has allowed scientists to piece together the mechanisms involved, and discover how different factors impact these mechanisms.

The following four cases—all examples of real impact arising from the application of neuroscientific research—highlight some of the ways in which these neuroscience technologies are transforming our understanding of how the brain learns.



Above:
Selected region of the
hippocampus of a mouse
brain, showing tau inclusions
(in white)—a shared feature
of many neurodegenerative
diseases.

Using functional
magnetic resonance
imaging (fMRI)
to understand how
we learn

With fMRI, researchers can measure brain activity by detecting changes associated with blood flow. It involves an individual lying in a very strong magnetic field (about 10,000 times the strength of the Earth’s magnetic field), which is then pulsed. The blood flow can be calculated based on how the field responds. This technology of fMRI allows scientists to detect which parts of the brain are activating or deactivating in response to learning, since learning (or any type of mental activity) involves changes in activity in different brain regions, with consequent changes in blood flow in those regions.

In one recent study in the UK, researchers looked at how “gamifying” learning can improve the rate at which students learn. Adult participants were asked to study a range of topics, from ancient history to mathematics. They experienced the learning through three modes: reading notes, as a self-test quiz game, and as a competitive quiz game involving escalating rewards won on a wheel of fortune. They were tested on their knowledge before and after their study session inside the brain scanner, and again a few weeks later. Researchers found that the more the learning was presented as a game,

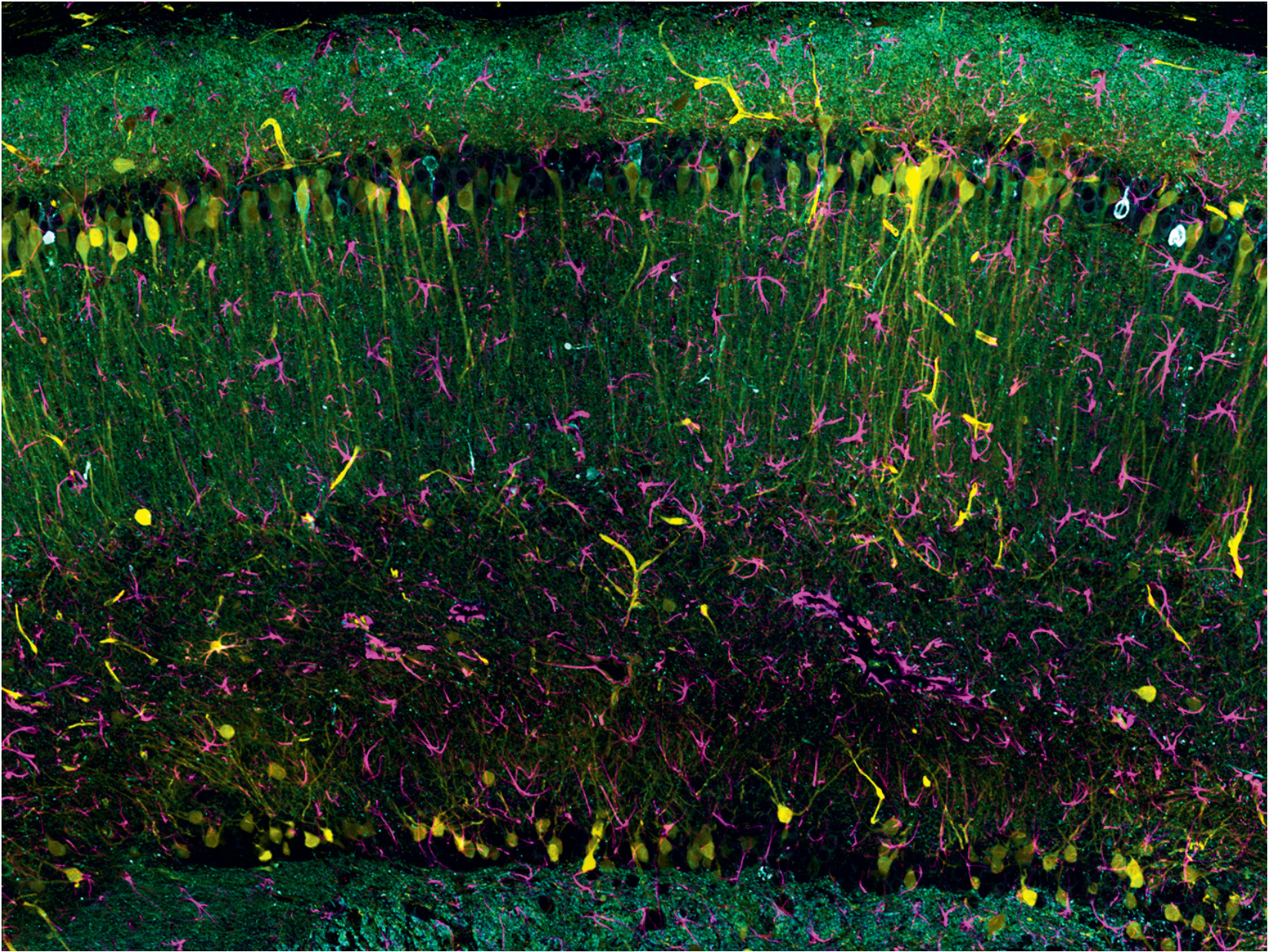
Researchers found that the more the learning was presented as a game, the more the rate of learning increased.

Below:
Lateral region of the hippocampus, showing pyramidal cells in yellow and protoplasmic astrocytes in magenta.

the more the rate of learning increased. At the same time, increased gamification also meant that less activity was observed in the brain network associated with mind-wandering, the so-called “default mode network”. In fact, students’ marks in a consequent test could be predicted by how much this mind-wandering network was inhibited. The game’s advantage for learning was that it kept students alert and focused on the external world in front of them, discouraging them from becoming lost in unhelpful reverie while studying. Activation of the default mode network may also be a helpful “marker” of engagement in future educational research of this type.

The growth in our understanding of how learning occurs in the classroom has immense potential value for educators. Teachers continuously make decisions that impact on their students’ learning, and it is simply not possible to furnish them with appropriate instructions for what they should do in every situation. Indeed, the extent to which a teacher simply applies prescribed good practice has been found to be a poor predictor of effective learning. Instead, teachers must be able to constantly select and adapt approaches based on their

own understanding of classroom learning. A scientific grasp of how learning happens can help here, supporting teachers in getting more out of their students. Gamification represents one very useful tool in doing this, and understanding how it works can help teachers gamify their lessons more effectively. Not surprisingly, teachers are now encountering learning concepts from mind and brain science in their initial teacher training and continuing professional development. There is more to be done, of course, but this constitutes important progress.



Training teachers to profile and promote brain development

The global picture, as you might expect, is mixed. However, some countries are doing notably more, including by training teachers to profile the brains of their students in order to support their development. There is now robust evidence pointing to the existence of specific brain networks responsible for basic capacities for learning mathematics and reading. These capacities may function as part of the “starter kit” for understanding numbers or written words, arising from the biology we are born with. This finding demonstrates the type of “usable knowledge” offered by neuroscience that has important implications for education. It supports the strategy of capitalizing on a student’s neurocognitive capacities whenever possible during instruction. Additionally, it suggests that teachers may be able to detect individual differences in how these capacities are developing in their students, if they are provided with the tools and training required. Teachers are among the best “cognitive enhancers” in the world, helping to change their students’ brains to acquire literacy, numeracy, reasoning skills and a complex range of further competences. Aligned with this, appropriate school-based interventions focusing on a neurocognitive approach are showing promise for

enhancing the learning potential of children, including those who develop atypically.

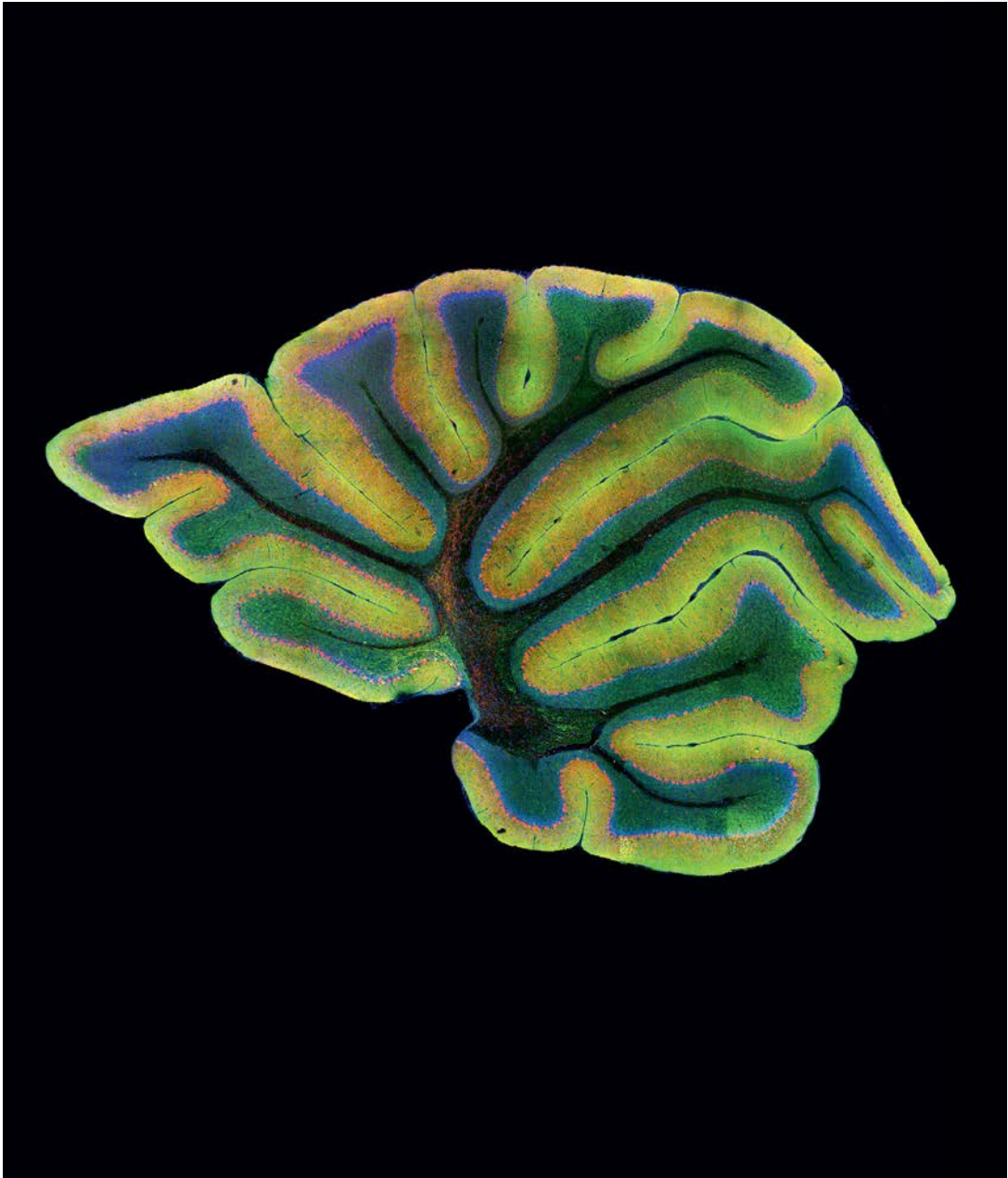
A school-based model for promoting neurocognitive development requires instruments and sustainable designs that fit global and local contexts. Researchers from the educational neuroscience lab at the Cuban Centre for Neuroscience have developed tools for profiling the neurocognitive status of children and for identifying early signs of atypical neurocognitive development. Such a neurocognitive profile facilitates intervention that focuses on individual differences in classroom learning contexts.

The model is supported by current technological advances. Tools for detecting “red flags” are based on mobile solutions, whereas tools for obtaining neurocognitive profiles are computerized tests that facilitate precision and accuracy in the assessment of neurocognitive processes. Both have been developed as client-server applications. Teachers are introduced to the main concepts about the brain and learning through an e-learning platform, using a theoretically guided video game in which they respond to cues for attending to individual differences in the classroom.

The advantages of integrating cognitive neuroscience knowledge with technology can also be seen in the development of new ways of remediating a broad range of developmental disorders. Claims about the general effectiveness of commercial programmes must be carefully scrutinised, but neuroimaging can help provide insight in cases where successful results are reported. For example, a study using an educational computer game based on neuroscientific understanding demonstrated the effects of remediation of problems with dyscalculia in terms of numerical performance and brain function.

When the cognitive and neural data converges in this way, we can be more confident in the effectiveness of the intervention and its underlying theoretical models. Understanding these underlying theoretical models is important for developing technology-based interventions that are effective in the classroom.

Above:
High-resolution,
wide-field mosaic
of the cerebellum.



Cognitive-based, digitally mediated interventions

One such intervention, in Uruguay, demonstrates just how important it is to have neuroscience and technology inform educational practice. Despite the optimism associated with technology as a learning tool, attempts to apply new technologies to education have often yielded only modest results. However, massive access to digital technology, the availability of a huge corpus of data and growing understanding of the concepts and theories of cognitive neuroscience are creating a wave of new, and hopefully more successful, technology-based educational interventions. Uruguay’s *Plan Ceibal* project, a scheme that gives one laptop or tablet to each school child, is an excellent example of this.

In principle, two kinds of interventions have the potential to improve educational outcomes; those designed to modify aspects of everyday life and those designed to be used in classrooms. In a study of the first kind of intervention, involving 700 children, researchers at the Universidad de la República (UDELAR) in Uruguay attempted to improve elementary maths performance by developing children’s approximate number system (ANS). The ANS is the brain system we use to estimate quantity without ac-

cessing mathematical symbols. The researchers devised a series of games to measure symbolic and non-symbolic maths abilities and used the game PANAMATH to train the ANS. The digital tablets of Plan Ceibal were used in a semi-supervised setting, within classrooms.

All of the children who took part in the study improved in their math tests after the intervention. The increase in performance was higher in schools with low socio-economic status (SES), thus demonstrating that an important tool for helping to close the digital poverty divide can be technology itself.

Another intervention, conducted by the same lab, focused on the study of the cognitive development of executive function in early childhood, in contexts of social vulnerability. The researchers attempted to improve children’s executive function through the use of Mate Marote (MM), a game developed by a team led by Mariono Sigman. Data showed SES was strongly associated with cognitive development. In particular, the performance of children with the lowest and the highest SES differed significantly in tasks of inhibitory control, cognitive flexibil-

ity, planning, fluid intelligence and working memory. After eight weeks of playing MM, children from vulnerable contexts achieved significantly better scores in inhibitory control and cognitive flexibility, and the increases were higher for children of the lowest SES schools.

Gamification may help transfer such an approach to situations where children play independently. The researchers at UDELAR are currently testing a prototype app co-created with professional game designers in order to train cognitive control, with the requirement that the game should be engaging for children. The results so far are highly encouraging.

The other type of intervention is to create activities that can be useful in a classroom setting. In line with this, the UDELAR researchers are collaborating with others to create a teacher-friendly platform, using robots to teach programming and so-called “computational thought” to pre-schoolers. They are also exploring the potential of technology to help teach functional programming to high school students and investigating whether this transfers to mathematics. These projects are not merely

Measuring arousal to detect “connectedness”

a new, fashionable techno-optimistic wave, but a genuinely motivated effort to bring what we know about cognitive neuroscience to bear in changing the core and periphery of educational practices.

What is particularly noteworthy about the interventions in Uruguay is that they are selecting and using technologies in a way that is informed by studies that have measured brain activity. In the future, it may be possible for educational technology to interface with the brain more directly. Such “neurotechnology” is becoming cheaper and more portable. It is already possible to see how portable methods of studying brain activity may become part of classroom practice.

Studies have shown, for example, that monitoring your own brain activity can help you achieve mental states that are more conducive to creative performance. Adults and school children have demonstrated improved musical performance after training using portable EEG equipment, and similar improvements in creativity have also been found among dancers. In the next few years, we can expect to see devices for measuring brain activity being used more in classroom research.

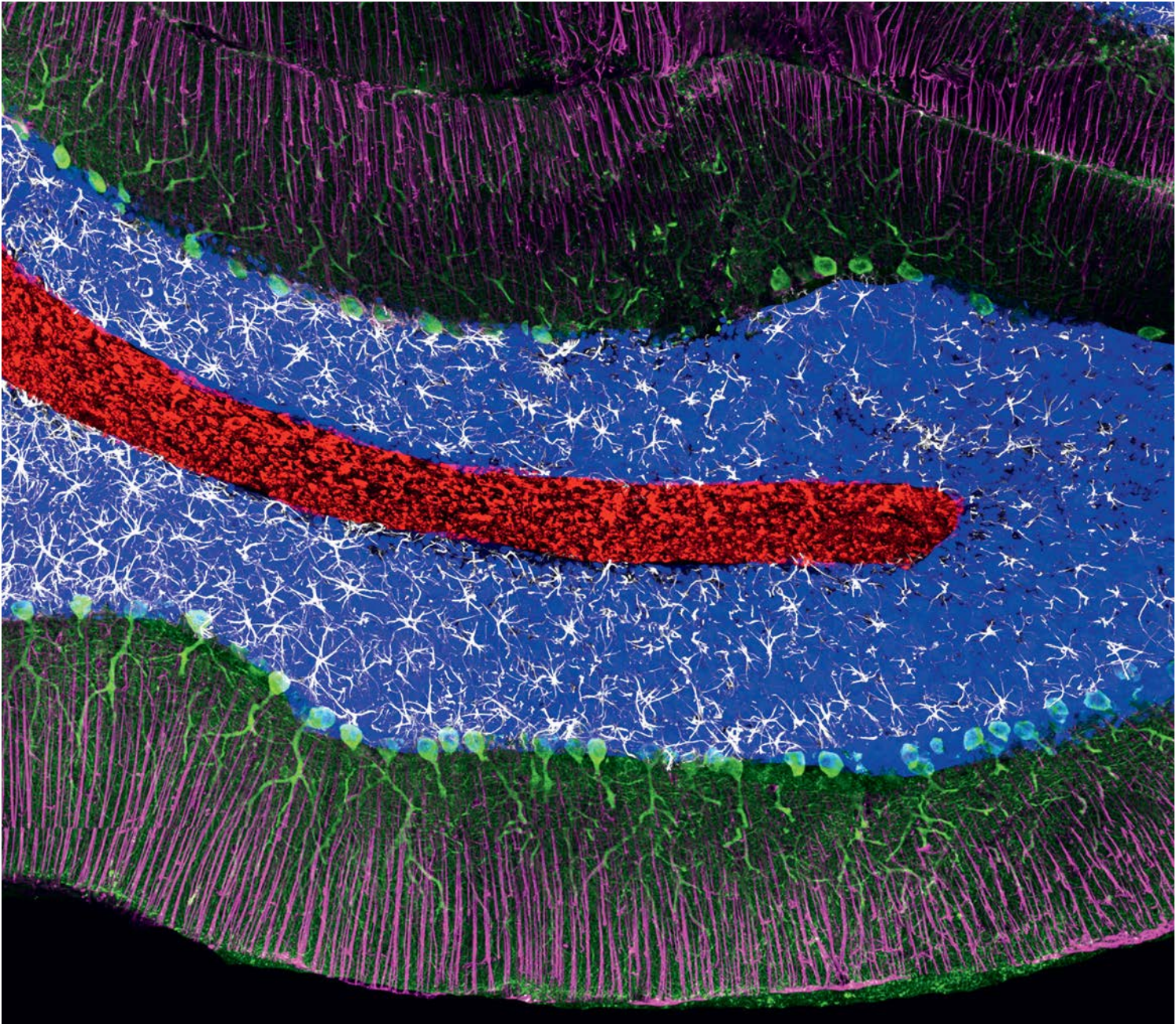
Some simple methods of measuring neurophysiological arousal in the classroom are already providing insights into behaviours that are important for learning. The classroom is a dynamic and highly social environment that features interpersonal interactions between students, as well as between teachers and students. Neuroscience and education researchers are increasingly interested in unobtrusive biometric measures of student engagement in learning, and measures of social interaction or social synchrony in the classroom represent an important factor that underlies successful co-operative learning skills and engagement in group learning activities.

Perhaps the best example of an unobtrusive recording device is the biometric wristband. These lightweight wristbands measure physical activity and the physiological responses of heart rate and sweating (also known as electrodermal activity) which change in response to various psychological and social processes, including arousal, emotional states and attention. A person’s physiological arousal level is measurable by changes in their heart rate and perspiration as they transition between arousal states on a spectrum of disen-

gaged, bored or fatigued at the lower end, to engaged and alert in the middle, through to anxious or stressed at the upper end. Dynamic changes in students’ arousal states, as they increase or decrease in physiological arousal in response to events or activities in the classroom, may represent changes in cognitive engagement or emotional state and can be assessed within particular types of pedagogical practice, or with particular student-student or student-teacher interactions.

A major challenge with biometric measurement is to devise computational methods that can answer research questions of interest to educators, or provide simple metrics that are meaningful and useful in relation to classroom learning or pedagogical practice. One very promising avenue, being explored in Australia, is to examine “connectivity” or synchrony between students through their physiological arousal levels. Such analyses examine the correlated changes in physiological arousal states between students during classroom learning, as biometrics such as heart rate or electrodermal activity appear to simultaneously change between people involved in cooperative work or positive social interac-

Right:
Example of a single tile,
wide-field mosaic of the
cerebellum.



In the future, it may be possible for educational technology to interface with the brain more directly.

The future of neuroscience and technology in education

tion. The Australian study found that synchronous fluctuations in physiology between students are typically greater when they are engaged in a common task or have a shared focus, such as the teacher during teacher-led instruction. This is a potentially powerful technique to quantify the extent to which students are “connected” with each other and their teacher, or with the ongoing events in the classroom environment.

These four examples demonstrate the huge potential contribution that the convergence of neuroscience and emerging technologies can make to education, through interventions based both in the classroom and in the wider life of the students. Already, it is making a significant difference to learners’ classroom performance and outcomes, as well as to their overall educational prospects, particularly for those from poor or vulnerable backgrounds. It is important to build on this good practice, in ways that are both informed and flexible. Technology is opening up new, often unanticipated, possibilities all the time.

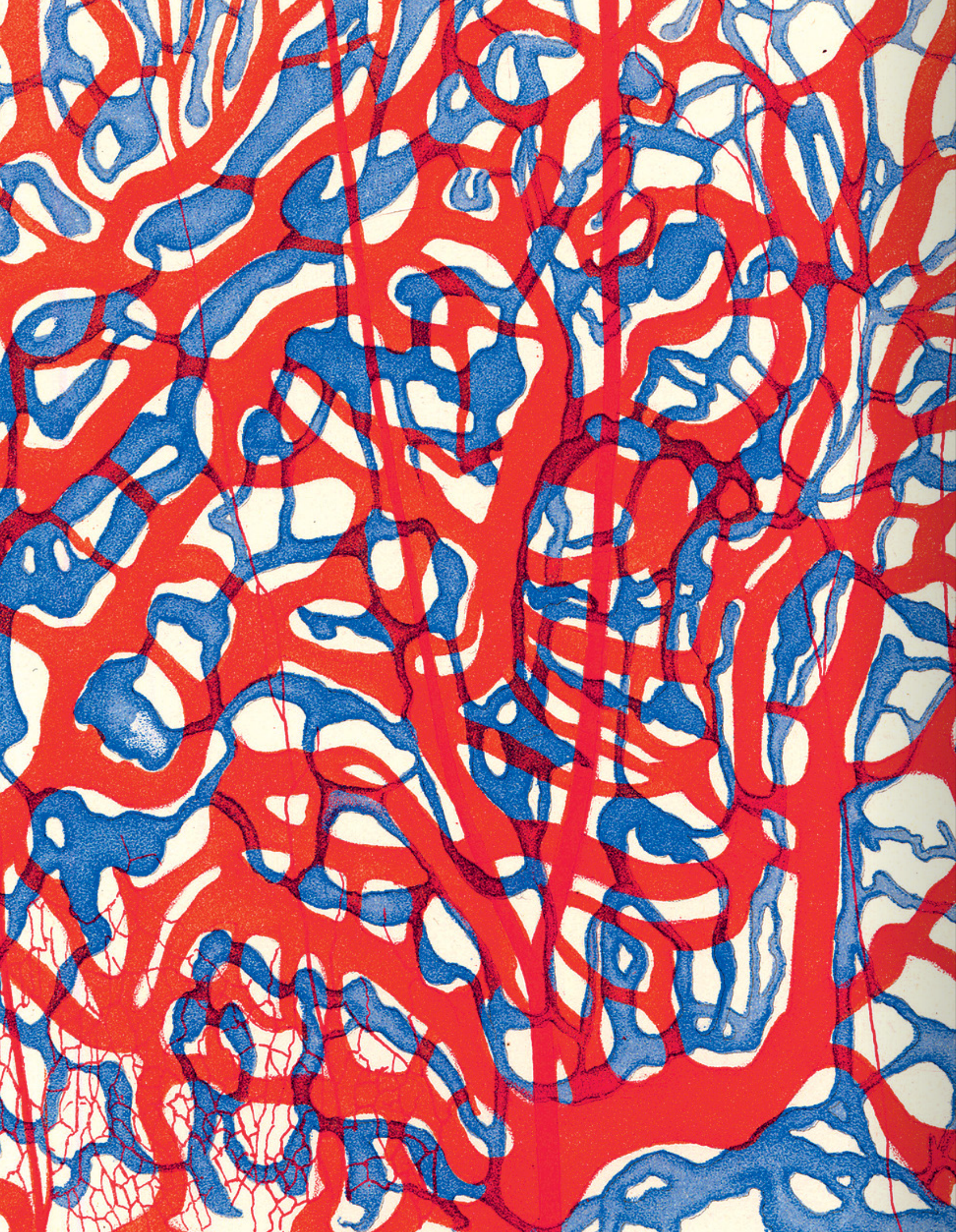
Our accumulating knowledge of the genetic, brain-based, psychological and environmental factors that predict learning may, one day, allow education to be tailored precisely to an individual’s needs. The technology for this important part of the “big data” revolution is not trivial, requiring improved portable neuroimaging for collecting brain data (e.g., neuroheadsets for EEG monitoring) and real-time processing of the data it produces. Gathering and interpreting an individual’s data may also require some further advances in genetic testing technologies. In all of these ar-

eas, however, technology is rapidly advancing, making the idea of personalized neuroscience-informed learning a realizable ambition for the future.

Combined with our understanding of cognitive neuroscience, technology is providing new ways to study learning in the brain, helping us identify those in need of extra help and supporting the development of new, scientifically informed technology in the classroom. Through the rolling programme of IBE-IBRO Science of Learning Fellowships, the IBE is looking forward to fully exploiting the opportunities and insights emerging from the fusion of these two exciting fields: education and neuroscience.



Technology is rapidly advancing, making the idea of personalized neuroscience-informed learning a realizable ambition for the future.



THE FORGOTTEN
HALF OF THE BRAIN:

G L I A L

AND THEIR
ROLE

C E L L S

IN LEARNING
AND MEMORY

by

Pierre J. Magistretti

Successive learning involves the same neural circuits, which help to create memory.

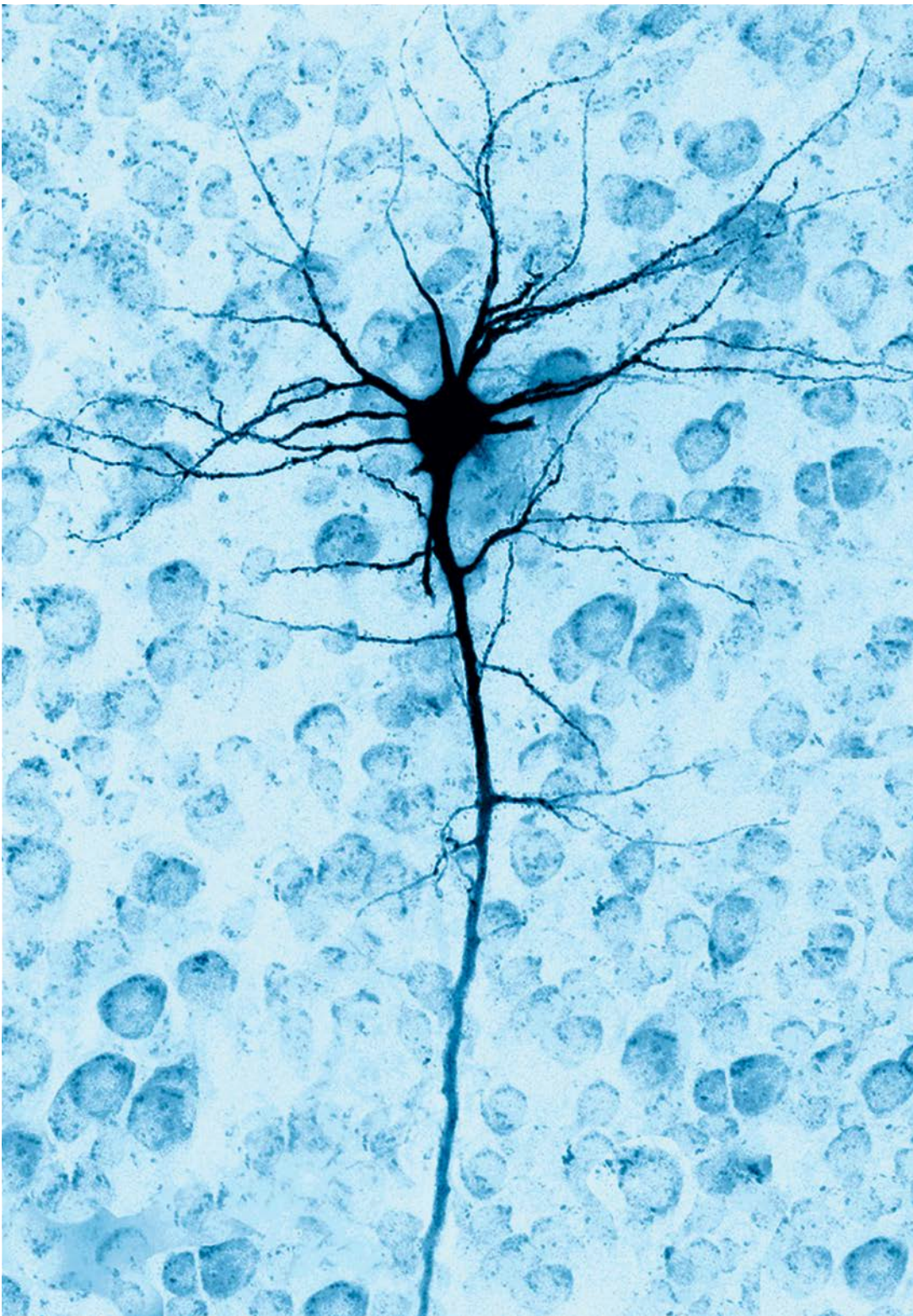
Opening image:
Study of the anatomy of the nervous system and connective tissues.
By
Gustaf Retzius (1842–1919).
Source: hagstromerlibrary.ki.se

What are neurons?

Neurons share many features with other cells in the human body, but they also have specific characteristics that underlie their functions. For example, they have several hundred extensions called dendrites. Dendrites receive inputs from other neurons at specialized points called spines. One of the extensions, which emerges from the cell body, is the axon. The axon ends in nerve endings, which come into contact with neighboring neurons. The human brain has around 85 billion neurons. As each neuron is connected to tens of thousands of other neurons, and sends about a thousand signals per second, it is estimated that the brain produces about a billion signals per second. Quite an amazing figure!

The space between each nerve terminal and the dendrites of the next neuron is narrow, about 200 angstroms, which is less than one millionth of a millimeter. This space is called a synapse. Neurons secrete from axon terminals a chemical substance called the neurotransmitter which is released in the synapse and binds to “receptors” located on the dendrites of the next neuron (Figure 1). It is therefore neurons that ensure the transfer of signals within the brain. There is, however, a

wide variety of neurons, probably several thousands, inspiring the Spanish neuroscientist Santiago Ramón y Cajal to rather poetically refer to them as “the butterflies of the soul”.



Above:
A single brain cell neuron.

What is the role of neurons in learning?

Neurons carry their messages in the form of electrical signals called action potentials. These are transmitted via the axon. Each action potential arriving at the end of a neuron (in the region of the synapse) triggers an activation or an inhibition response on the next neuron (on the opposite side of the synapse). The strength of these signals can vary.

Neurons are constantly changing. They are malleable enough to change the distribution of nerve connections as needed. During learning, sets of neurons change their configuration by multiplying synapses and making them more efficient to facilitate nerve transmission. This phenomenon is known as synaptic plasticity.

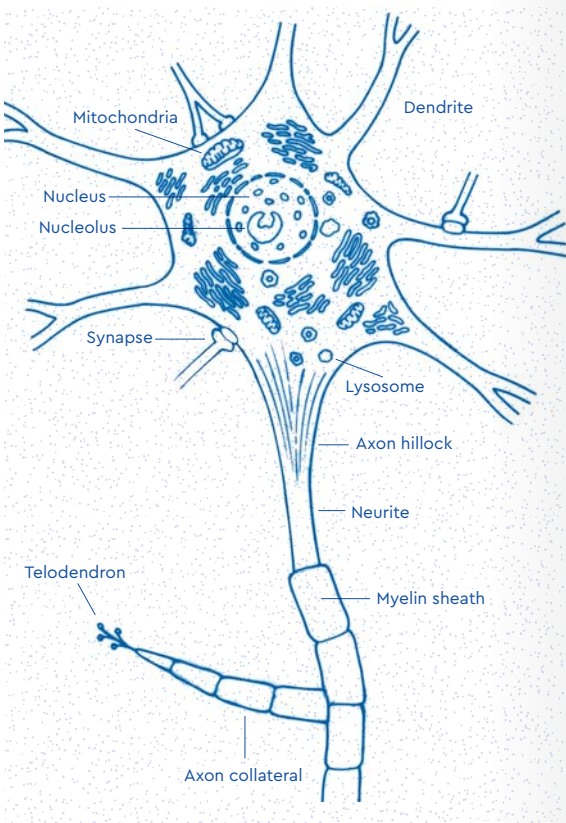
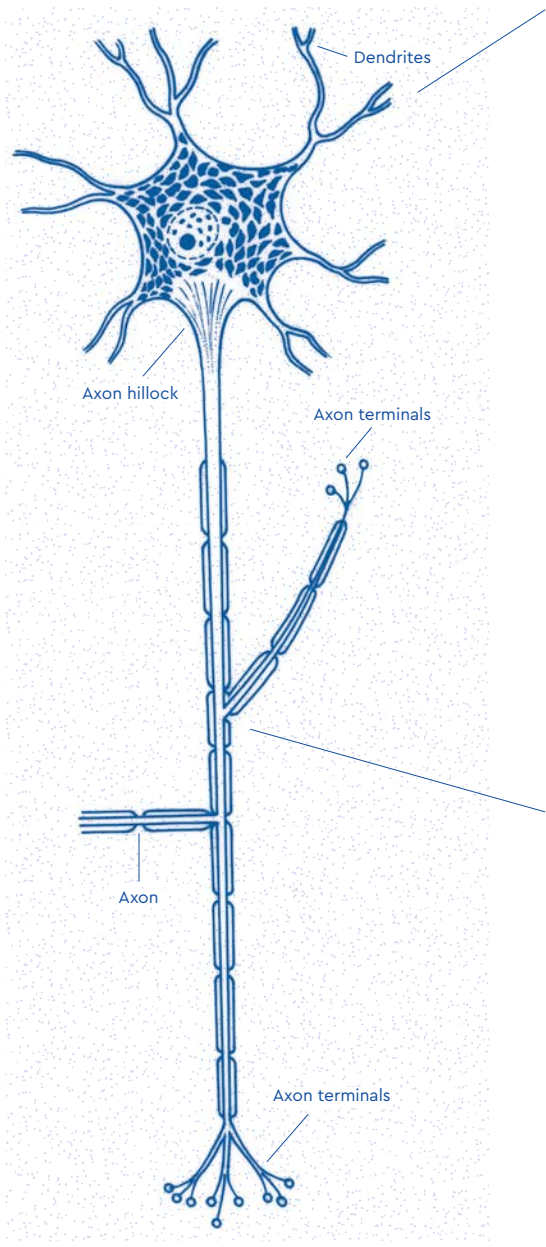
To ensure the transfer of new information, these new connections are made on demand. When information is repeated, the resulting neuronal signals are not randomly distributed. Instead, they tend to follow existing pathways. Everything happens as if the information has to go through the newly remodeled synapses repeatedly. As such, it is said that synapses are “strengthened”. Successive learning involves the same neural circuits, which help to create memory.

More on the architecture of the learning brain: Glial cells

At the frontiers of neuroscience research, it was recently discovered that neurons are not the only cells in the brain that are essential for learning. In certain species such as humans, there are at least as many non-neuronal cells, called glia.

Until recently, glial cells were considered to be a sort of “glue” that holds neurons together, a connective tissue of the brain. Over the past two decades, research on glial cells, particularly on a specific type called the astrocyte, has revealed the key role they play in brain function. Astrocytes provide energy for neurons and support synaptic plasticity during higher brain processes such as learning, memory and cognition.

The human brain contains slightly more glial cells than neurons, about 85 billion. The number of glial cells is slightly higher, more than 100 billion. The number and complexity of glial cells increase more with evolution and biological complexity than is the case with neurons. For instance, in a leech there is a single astrocyte for every 30 neurons. In an earthworm, there are six times more neurons than glia. In a rat the ratio of glia cells to neurons is 0.6:1, while in humans there



Above: Figure 1
Schematic representation of neurons, their processes (dendrites and axons) and synapses.

Left: Figure 2
Schematic representation of an astrocyte.

At the frontiers of neuroscience research, it was recently discovered that neurons are not the only cells in the brain that are essential for learning. In certain species such as humans, there are at least as many non-neuronal cells, called glia.

are 1.5 glial cells per neuron. This suggests that glia density may be related to higher brain functions.

Glial cells were first described by the German neuropathologist Rudolf Virchow in 1856. He described a non-specific tissue, considered connective, that was interposed between the nerve cells and blood vessels. He concluded that this substance, which he called “neuro-glia”, was a kind of cement (“Nervenkitt”) that held the cells together. Towards the end of the nineteenth century, Camillo Golgi and colleagues proposed that glial cells play a role in the distribution of nutrients to neurons from the bloodstream.

Astrocytes take their name from the fact that they have many features that make them look like stars (in Greek, “astros” means “star”) (Figure 2). Astrocytes have specialized processes called end-feet that are in contact with blood capillaries, which in turn deliver energy to the brain (sugar and oxygen). A single astrocyte can contact hundreds of thousands of synapses. This means that astrocytes have the capacity to detect synaptic activity and couple it to the energy supply in the brain.

Furthermore, astrocytes express receptors and reuptake sites that recognize neurotransmitters released at the synapse, particularly glutamate, which is the most common signal of neuronal activity released by 80% of synapses. When glutamate molecules are released at the synapse, they transmit information to other neurons and are quickly recorded by the astrocyte. When astrocytes detect synaptic activity, a series of metabolic processes is triggered that allows them to import sugar from the bloodstream and deliver energy to neurons. It turns out that astrocytes somehow “pre-digest” glucose (the main sugar in the blood), transforming it to lactate that can readily be used by neurons.

The classical view of neural communication mediated exclusively via synapses has expanded to include communication between neurons and astrocytes. In addition to lactate, astrocytes release other molecules that act on neurons and can even modulate synaptic activity. A new term has been coined to reflect this type of communication: gliotransmission (as opposed to neurotransmission). Astrocytes act as modulators of synaptic transmission. In some cases, glutamate released by a neuron

acts not only conventionally on another neuron, but also on the receptors present in the astrocytic processes that surround the synapse. The astrocyte in turn releases glutamate which amplifies synaptic transmission between neurons. The astrocyte thus acts as a sort of “turbo charger” for synapses. Glutamate released by astrocytes can also act on an ensemble of neurons and thus synchronize their activity.

The understanding of memory exclusively in terms of neurons has now been challenged, as more evidence indicates that glial cells, in particular astrocytes, also contribute to memory.

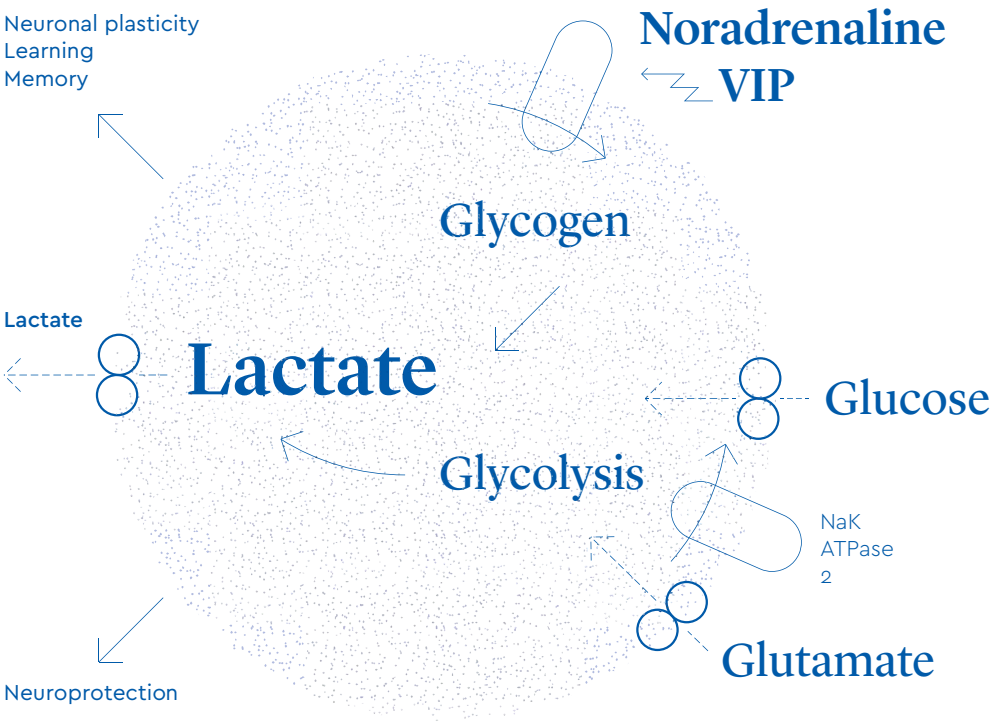


Figure 3:
Schematic representation of neuron-glia interactions, highlighting the role of astrocytes-derived lactate in physiological functions.

Emerging evidence on the role of glial cells in learning and memory

The conventional view of that, solely based on communication between neurons, is largely outdated. The neural and astrocytic networks engage in an intense dialogue via chemical signals, neurotransmitters, and gliotransmitters. This dialogue also highlights the role of astrocytes as integrators of neuronal activity.

Granted, neurons, through their remarkably efficient signaling capacities at the synapses, are essential to the transmission of information. The mechanisms of synaptic plasticity, which strengthen the transmission of information between groups of neurons, can be strengthened, and form a biological substrate for learning and memory. However, the understanding of memory exclusively based on neurons has been challenged, as more evidence indicates that glial cells, in particular astrocytes, also contribute to memory.

Astrocytes have a variety of properties that explain why they are critical players in memory and cognitive processes. For instance, they can sense and power synaptic activity. They produce molecules that can strengthen synaptic communication and they can synchronize the activities of groups of neurons involved in the learn-



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ing process. Note that a single astrocyte can contact nearly 2 million synapses in human brains but only 100,000 in those of rodents. Interestingly, transplanting human astrocytes into the brain of newborn mice allows grafted animals to learn faster and to have increased memory capacity.

In a series of experiments carried out in my laboratory and in collaboration with other laboratories over the last decade, we have demonstrated that signals released by astrocytes are necessary for memory consolidation. Thus when, with appropriate pharmacological tools, we hampered the transfer of lactate from astrocytes to neurons in the hippocampus—a brain region critical for memory—we were able to block memory consolidation of a learning task in rodents. This lactate originates from glycogen, the energy storage form of glucose contained in astrocytes. It is noteworthy that they are the only cells in the brain that have this property.

Initially we thought that the role of lactate in memory consolidation was that it was acting as an energy substrate for energy-demanding tasks that underlie synaptic plasticity. However, we discovered that the lactate released by glial cells involved another

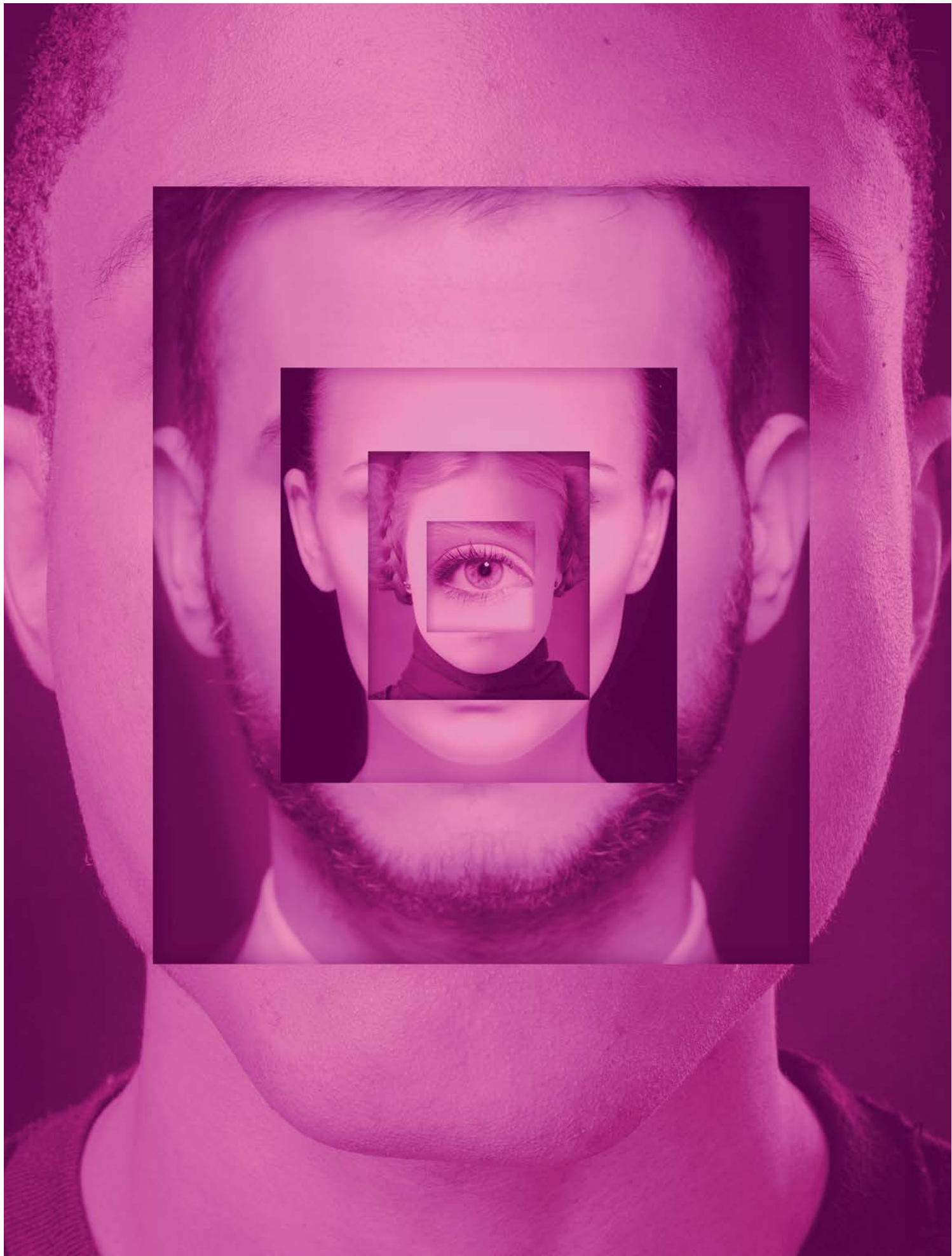
property of lactate, namely the increase in the expression of genes necessary for synaptic plasticity.

Where are we and what is next?

These results demonstrated for the first time that a glia-derived molecule is necessary for memory consolidation. This is a much more auspicious role than “brain glue”. Similarly, we revealed that lactate, a molecule long considered as a metabolic end-product, plays a vital role in memory function (Figure 3).

We are now working to discover drugs that could promote the formation of lactate from astrocytes to increase memory performance in normal, as well as in pathological conditions such as dementia. Perhaps with time, such memory performance can be applicable to learning, especially the learning of complex tasks. Even for lower-level tasks, enhanced memory performance could improve the automaticity of task performance in order to release short-term memory for higher-level tasks.

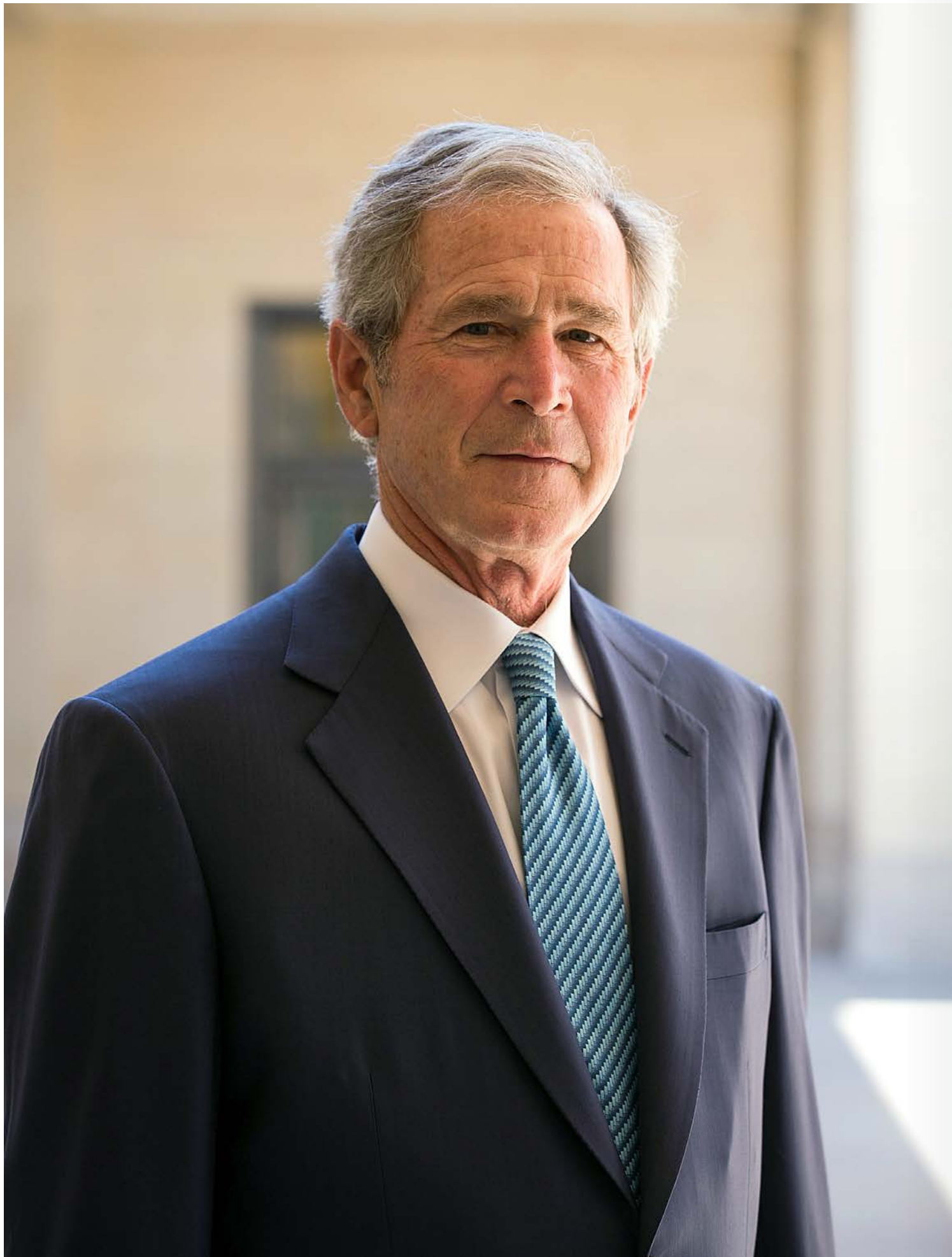
There is no doubt that much research still remains to be done to identify all the cellular and mechanisms of memory consolidation, but those efforts must not only consider neurons but also glial cells as potential sites of action.



THE
↓
C H A L L E N G I N G
↑
FUTURE

**OF EDUCATION AND LEARNING:
WHAT CAN NEUROSCIENCE AND
TECHNOLOGY CONTRIBUTE?**

Better leveraging of emerging technologies and neuroscience can help us attain and sustain quality and development-relevant education and learning for all. Let's take a closer look at advances in the science of learning (SoL), especially neuroscience, and see why they matter to the future of education and learning.

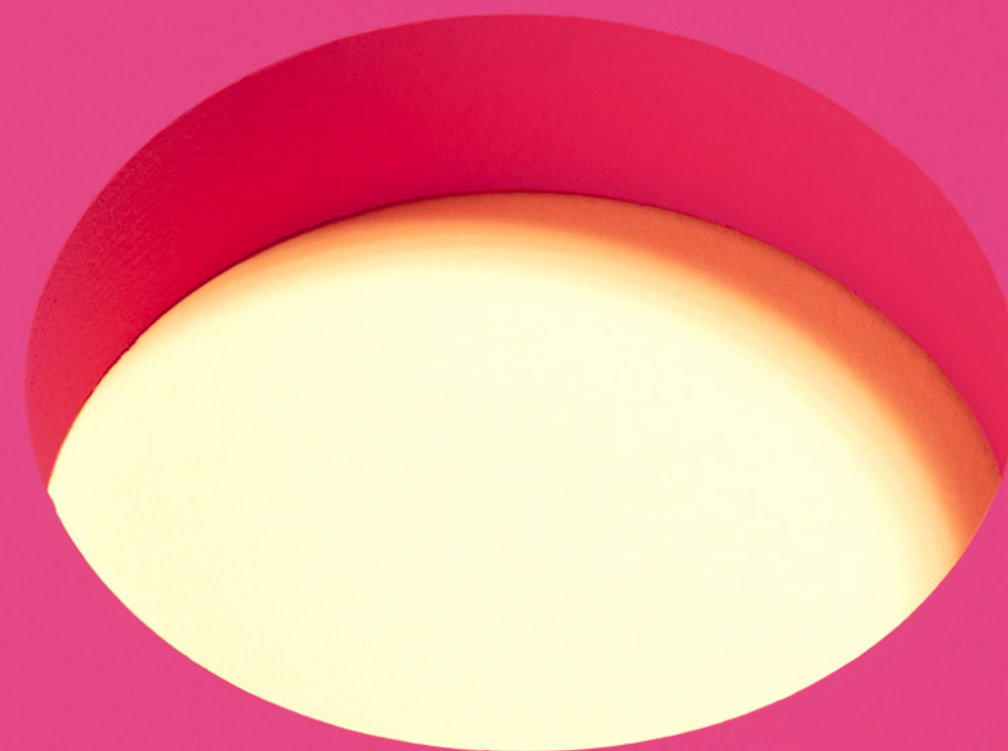


We owe every child the pride and promise of learning. Our new economy—requiring higher and higher skills—demands it. Quality education for everyone, of every background, remains one of the most urgent civil rights issues of our time.

George W. Bush
Former President of the United States



ADDRESSING THE GLOBAL LEARNING CRISIS



HOW CAN COGNITIVE NEUROSCIENCE HELP?

by

Mmantsetsa Marope



L

Living is learning just as learning is living. Learning is what gives all species adaptive competence and the resilience to survive, live, prosper, and thrive. Since ancient times, people have developed processes to select what is important to learn, when and how to learn it, and why they should learn it. A refinement of these processes is what ultimately separates informal learning, which is truly lifelong, from formal learning, which strives to be lifelong.

The ancient Egyptians (3000–500 BCE) were the first to institutionalize formal education with a curriculum comprising religion, language, communication, trading customs, and agricultural practices. Since its inception, the core mandate of formal education has been to facilitate the learning of what society (initially the upper class) considers important to know. Though learning has always been the *raison d’être* of formal education, the past two decades have witnessed an unprecedented focus on human learning and its heightening recognition as the core purpose of formal education systems.

Why the Renaissance of Learning?

Underlying the learning renaissance are the relentless, unpredictable, fast, progressively complex, and disruptive contextual changes typical of the 21st century. Key drivers of change include:

- *globalization and escalating demand for a wider and more complex set of competences;*
- *demands of global and local citizenship and the associated widening range of contexts to which people must continuously adapt through learning;*
- *the emergence of knowledge-based economies and growing labour market demand for knowledge workers;*
- *Industry 4.0 and associated dramatic changes in workplaces and life-contexts, both of which demand higher and complex competences that have to be sustained through lifelong learning;*
- *ease of communication and travel, as well as growth of forced and voluntary migration and consequent dramatic changes in life contexts;*
- *shorter and higher innovation cycles that constantly change life as we know it;*
- *internal and external vulnerabilities (natural or human-made), such as climate change, recurring epidemics and pandemics;*
- *the global equity imperative that recognizes learning and continuous development as basic human rights;*
- *internationally agreed goals (IAGs) for education that rally the world around the actualization of the right to learn and develop; and, most of all,*
- *an acknowledgement of the global learning crisis.*

Combined, these change drivers can quickly render what people have learned and their set of competences for life and work obsolete. Keeping one’s set of competences requires constant upgrading, re-learning, and self-renewal; all of which depend on effective lifelong learning. Yet, the paradox of our time is that as lifelong learning becomes an indispensable source of individual, collective, national, and global resilience, education



and learning systems are abysmally failing to produce effective lifelong learners. A phenomenon called the global learning crisis has crept into the discourse of the global education community; while impactful measures to address the crisis remain elusive.

Evidence of the global learning crisis

Internationally Agreed Goals (IAGs) tend to draw collective attention to challenges common to humanity. The Education for All (EFA) movement (1990–2015) perhaps represents the tipping point in terms of an unprecedented expansion of access to formal basic education. However, diverse sources have shown that, for many learners, enrolment in schooling does not translate into effective learning. By the end of the EFA term, 250 million children of primary school age still lacked the prerequisites for basic learning, such as sustainable literacy and numeracy, even though at least 130 million of these students had had four years of schooling. This signaled very serious consequences for learners’ capacity for effective lifelong learning, considering that virtually all forms of learning require reading with comprehension.

In 2016, the OECD reported that more than one in four 15-year-old students from countries participating in the 2012 Program for International Student Assessment (PISA) did not attain baseline proficiency in at least one of the three core subjects, mathematics, read-

ing, and science. Longitudinal analysis of performance within the PISA study showed that, in 39 countries where learners struggled with mathematics, the percentage of students underperforming improved only slightly from 22.1 to 21.5 over a decade—2002 to 2012—suggesting a near stagnation of learning outcomes. A presentation of the 2015 PISA results showed that, for the majority of participating countries with comparable data, performance remained essentially unchanged since 2006, despite significant advances in science and technology over the period. On average, nearly a fifth of students did not attain baseline proficiency in reading, and this proportion has held steady since 2009. More promisingly, a twenty-year analysis of Trends in International Mathematics and Science Study (TIMSS) showed improvement in 4th and 8th grade mathematics achievement in 13 of the 17 countries providing longitudinal data.

As evidence mounted, global dialogue on education began to focus on learning. Titles of sector strategies, policy papers, and position papers of major development agencies spoke more of “learning” and less of “education”. Technical reports also called more attention to learning, and to the rude awakening that schooling does not necessarily assure learning. Learning also became a leitmotif of such major conferences as the 1990, 2000, and 2015 World Education Forums and Education Fast Forward debates of the Education

to find effective ways to push back. Two years into the monitoring of SDG4.1, UIS estimated that 617 million primary and secondary students, nearly 60% of the total worldwide, were not achieving minimum proficiency levels in reading their native languages or doing age-appropriate mathematics.

What can cognitive neuroscience offer?

Research findings from cognitive neuroscience can provide valuable insights with potential to engender more effective facilitation of learning. However, like any young field, it is not without its critics. On one end are arguments that come uncomfortably close to discounting any potential for neuroscience to contribute to effective teaching and learning practices. On the other are arguments that, because of the centrality of the brain to learning, cognitive neuroscience is indispensable to everything to do with teaching and learning. In the middle are cautious voices that call for rigorous and scientific verification of findings as well as painstaking piloting in education settings before drawing conclusions on how cognitive neuroscience can contribute to more effective classroom practices.

Arguments against the applicability of neuroscience

In his most cited work, *Education and the Brain: A Bridge Too Far* (1997), John T. Bruer argued that efforts to link neuroscience and classroom practices were failing because they were trying to build “a bridge too far”. He argued that neuroscientific findings are applicable to cognitive psychology, which in turn, is applicable to education practices, including at the classroom level. He posited that “there [was] however, a science of mind; cognitive science that can serve as a basic science for the development of an applied science of learning and instruction. Practical well-founded examples of putting cognitive science into practice already exist in numerous classrooms. Teachers would be better off looking at these examples than at speculative applications of neuroscience”. However, towards the end of his argument, he characterized the building of the bridge between neuroscience and education as a work in progress. He noted that “educational application of brain science may come eventually, but as of now [writing in 1997], neuroscience has little to offer teachers in terms of informing classroom practice”.

Neuroscientists Cayce Hook and and Martha Farah (2012) also cast doubt on the classroom applicability of neuroscience, but accepted its potential relevance to education in general. They concluded that it is no longer in doubt whether neuroscience has provided a scientific context for thinking about education and learning. What is still arguable, in their view, is the extent to which the findings that neuroscience provides are directly relevant to what teachers do.

In their revisit of Bruer’s thesis, Jared Horvath and Gregory Donoghue (2016) acknowledged gallant efforts to link findings from neuroscience with instructional practice, but still described an effective neuroscience/education bridge as a “frustrating chimera”. They warned that a dogged pursuit of a prescriptive bridge

Research findings from cognitive neuroscience can provide valuable insights with potential to engender more effective facilitation of learning.

FOUR BRIDGES

THAT CAN
CONCEIVABLY
BE BUILT
BETWEEN
NEUROSCIENCE
AND EDUCATION:

1

The prescriptive bridge

2

The conceptual bridge

3

The functional bridge

4

The diagnostic bridge

(Horvath and Donoghue, 2016)

between the two disciplines was adding to the proliferation of the very neuromyths that Bruer had cautioned against. They elaborated on Bruer’s idea of a neuroscience/education bridge by identifying four types of bridges.

The first is a prescriptive bridge that attempts to specify practices to be undertaken at the educational level based on evidence derived from neurophysiology. Essentially, this is an attempt at a prescriptive translation aimed at instructing an educator and a learner on what to do and how to do it.

The second type is a conceptual bridge which allows individuals to understand or conceive of phenomena at the educational level through theories generated at the neurophysiological level. That is, a conceptual translation that allows educators and learners to broaden their explanations for, and interpretations of why certain educationally relevant practices work. However, this type of translation is silent on what said practices should or should not entail. For instance, although some educators may be inspired to use the concept of Hebbian plasticity to justify the success or failure of a specific lesson, this interpretation does not affect the content, form, or efficacy of the lesson itself.

The third type of functional bridge allows for phenomena at the neurophysiologic level to constrain behaviors and cognitions at the educational level. This translation allows for alterations of brain form and/or function to expand or restrict the number and type of educationally relevant practices an educator or learner can successfully undertake. Again, this is silent on what said practices should or should not entail. For instance, if a learner were to suffer damage to the visual cortex leading to blindness, then any learning activities would be unavoidably constrained to activities that do not rely on vision (education). Of particular importance in this example, is that damage to the visual cortex does not instruct the learner as to which non-visual learning activities to undertake, how to best undertake them, or how to measure their impact.

Horvath and Donoghue (2016) acknowledged the subtle distinction between prescriptive and functional bridges and illustrated that difference by way of example. For instance, some students with attention disorders may opt to use pharmaceuticals to mitigate their symptoms and improve educational performance. This performance is improved by changing activity at the neural level. At first glance, the use of a pharmaceutical may appear to be a prescriptive bridge. However, a closer examination reveals that taking a pill constrains an individual’s attentional networks thereby making them more receptive to learning—but this does not engender learning itself. Pharmaceuticals do not inform educators or learners of activities to use or how to use them in order to engender learning. Consequently, a pharmaceutical intervention represents a functional, rather than a prescriptive, bridge.

The fourth type of bridge is the diagnostic bridge. This allows for cognition and/or behavior at the educational level to be backward-mapped to, and correlated with phenomena existing at the neurophysiological level. In other words, diagnostic translation aims to



Facilitating dialogue between educators and neuroscientists could help increase the focus on learning, provide a first line of defense against neuromyths, and support professionalism by empowering teachers with a scientific understanding of teaching and learning.

describe how a student is learning (or failing to learn) based on individual functional brain patterns. Once again, although this type of translation may inspire novel ideas for learning interventions, it is silent on what these interventions should be and how they should be enacted. For instance, if a learner were to demonstrate difficulty engaging with a reading lesson (education), knowledge of his/her neuronal activation patterns during reading activities (neurophysiology) could be utilized to potentially determine the underlying root/s of this difficulty. Of importance here is that this knowledge does not inform an educator or student on what to do to effectively to improve or otherwise alter said neuronal patterns.

Horvath and Donoghue (2016) agreed with Bruer that the prescriptive bridge that educators seek is still a bridge too far. A bit more harshly than Bruer, they sought to demonstrate why, practically and philosophically, attempting to prescriptively connect neuroscience and education was both hollow and irrelevant. As such, teachers, being already overburdened with work, should not be expected to understand neuroscience, which ultimately has no direct impact on the skills essential for success in their profession, unless such teachers are personally interested in the subject.

In their endeavor to prove why findings at a neuroscientific level are irrelevant, and cannot be prescriptively translated to classroom behaviors, Horvath and Donoghue claim that prior efforts were wasted on trying to create a bridge between non-adjacent levels-of-organization—neuroscience and education. They advise researchers who are interested in a prescriptive translation of neuroscience findings to education to rather invest time in mastering the links between adjacent levels—neuroscience and psychology or psychology and education—because it is between such adjacent levels that meaningful prescriptive translations are feasible. As with Bruer (1997), their theory of prescriptive applicability across adjacent

levels does not mean that knowledge of the brain is useless in the classroom setting because it does confer opportunities for conceptual, functional, and diagnostic translation.

Jeffrey Bowers (2016) also dismissed the applicability of neuroscience, arguing that it failed to generate new and specific approaches to teaching or to learning. He asserted that instead of bringing new knowledge, neuroscience has only brought evidence for what psychology has already provided.

Other skeptics of the applicability of neuroscience have pointed to the distance between controlled laboratories where neuroscience is studied and real-life classrooms. They highlighted the long way from the neuron to the neighborhood (Shonkoff and Phillips, 2000). Horvath et al. (2017) also contended that answers found within a neat laboratory are rarely directly applicable to a messy classroom, but at the same time, they acknowledged that it is for this very reason that the Science of Learning (SoL) field was created. They identified four key objectives of the field: “determination of learning principles that are general and adaptable to context, correlation of learning principles with current practice, generation of novel practices, and elucidation of the biological processes of learning”.

Further skepticism about the applicability of neuroscience findings to education practices arises from the reality that the nature of the research is often micro-modular in terms of scope while teaching and learning are complex and multifaceted. Research often focuses on specific aspects underlying specific learning processes rather than on holistic improvement of education or learning, which is far more multifaceted and complex. Insights from SoL—including neuroscience—therefore produce discrete pieces of evidence on molecular aspects of complex processes such as learning.

Arguments for the applicability of neuroscience research findings

In 1983, Leslie Hart came close to saying that an understanding of the brain was a prerequisite to the design of any educational experience. He drew the analogy that designing educational experiences without an understanding of the brain was like designing a glove without an understanding of the human hand. A 2011 report by the UK Royal Society reinforced the potential of neuroscience to transform education and learning, stating that “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” (Howard-Jones et al., 2016). Mayer (2008) further described the link between neuroscience research findings and education practice as reciprocal and not unidirectional, such that “Understanding how people learn helps researchers identify instructional design features to be tested for effectiveness, and evidence concerning effective (and ineffective) instructional designs can be used to test and improve theories of how people learn”.

EDUCATORS’
ACCESS

TO INSIGHTS
FROM
NEUROSCIENCE
IS CONSTRAINED
BY:

Limited
literal
or physical
access

•

Limited
substantive
access

•

Challenges
of scaling up
promising
applications of
neuroscientific
knowledge

•

Limited
transfer to
global education
policy and
practice
stream.

From an extensive review of research, Paul Howard-Jones (2017) concluded that we now have sufficient knowledge to begin explaining and promoting core classroom learning practices using scientifically informed concepts of learning. Moreover, since teachers are responsible for their students’ learning and the brain is central to learning, teachers’ enthusiasm for applying neuroscience to improve their facilitation of students’ learning is justified (Howard-Jones, 2017). He and others advise that facilitating dialogue between educators and neuroscientists could help increase the focus on learning, provide a first line of defense against neuromyths, provide an authentic foundation for insight and practice, inform classroom implementation of reforms, and support professionalism by empowering teachers with a scientific understanding of teaching and learning. As such, the idea that our understanding of how the brain works could affect education practice is persuasive.

Dartmouth University’s undergraduate education degree in educational neuroscience (EN), founded in 1990, is among the earliest efforts undertaken to close the communication gap between educators and neuroscientists (Tokuhamma-Espinosa, 2011). In 1998, Cornell University established the Sackler Institute for Developmental Psychobiology, which in later years, progressively focused on EN. From 2000 onwards, many more universities in Europe, East Asia, and North America established EN, mind, brain, and education (MBE), and Psychology and Neuroscience programs. Examples include: Harvard University, in 2001/2002; University of Cambridge, in 2004; Transfer Center for Neuroscience and Learning in Ulm, Germany, in 2004; Bristol University, in 2005; and the Learning Lab in Denmark, in 2005 (Tokuhamma-Espinosa, 2011). Other academic programs in MBE science by 2005 include those at the University of Texas at Arlington, the University of Southern California, Beijing Normal University, and South East University in Nanjing.



Translation work has difficulty reaching a large base of educators, especially those in the least developed countries and in disadvantaged contexts of developed countries. Yet, these are contexts where the global learning crisis is deepest, and where educators need insightful inputs from every credible source.

Academic programs and intellectual dialogue in EN, MBE, and in Psychology and Neuroscience took off in earnest in 2000, backed by research institutes, major conferences, publications, and significant government investment in studies of the transdisciplinary link between psychology, neuroscience and education. Since then, the field has continued to flourish, strengthening the scientific rigor underpinning neuroscientific knowledge about learning, and dramatically improving the credibility of neuroscientific information written for and by educators (Tokuhamma-Espinosa, 2011; Howard-Jones, 2017). With growing interest on both sides, the transdisciplinarity and collaboration between educators and neuroscientists has improved, while the credibility of neuroscientific insights has deepened. Case materials on relevant applications of neuroscientific insights in classroom settings are fast accumulating, especially when considering that the field (EN/MBE) spans only three decades.

So where does the debate leave us?

The nub of the debate is whether or not we can look to neuroscience for a significant contribution to addressing the global learning crisis. My take is that we can and we must. As frontline facilitators of learning, teachers must optimally use insights from neuroscience to improve their effectiveness, and by implication, student learning. Thus far, extant literature offers no compelling evidence for us to discount the potential contribution of neuroscience to improving the effectiveness with which educators facilitate learning.

To start with, Bruer (1997) never claimed that there was no bridge between neuroscience and education practices. All he ever said was that at the time of his writing, the bridge was not yet established. Granted, at times, he went so far as to suggest that looking towards neuroscience for insights to improve the facilitation of learning was a waste of time. But, on a positive note, he presented the applicability of neuroscience to education practices as work in progress, by admitting that “educational application of brain science may come eventually”. Even at that time when he perceived the bridge to be too far, he proposed that cognitive psychology could be the intermediary link between neuroscience and education practices.

In a similar vein, Horvath and Donoghue (2016) argued that a search for direct applicability of neuroscience to education practices—the prescriptive bridge—was hollow and irrelevant. But they concurred with Bruer (1997) that effort was best spent on mastering the links between adjacent levels—neuroscience and psychology or psychology and education—because it is between such levels that meaningful prescriptive translations are feasible. They also observed that three of their proposed bridges—conceptual, functional, and diagnostic—already existed in classrooms.

Bowers’ (2016) criticism that neuroscience hasn’t led to new approaches to education practices but has only brought more evidence to what psychology already provided, is hardly a reason for discounting the applicability of neuroscience to classroom practices. Neuroscience raises the value of, and confidence around psy-

The potential contribution of neuroscience has to be unleashed, and tried and tested contributions applied to enrich teacher insights into the effective facilitation of learning.

chological understanding of what works. For instance, understanding neuroscientific underpinnings of their effective practices should boost teacher confidence to continue and even share such practices. Credible scientific evidence is particularly important in this era where evidence-based policy and practice is the mantra.

Discounting the applicability of neuroscientific knowledge to real-life classrooms on grounds that such knowledge is conceived out of controlled laboratories (Shonkoff and Phillips, 2000; Horvath et al., 2017) hardly squares with common experience. Virtually all scientific and technological breakthroughs that drive innovation and change came out of controlled laboratory environments. The fact that Pavlov’s classical conditioning happened in neat cages where dogs could associate the presentation of food with the sound of a bell did not stop the application of his findings to classrooms practices. The use of positive reinforcement—or in more sophisticated terms—positive feedback, incentives, or praise is now commonplace in classrooms, workplaces, and in life in general. It is difficult to see why, over time, and with sufficient testing and contextual adaptations, knowledge generated in controlled neuroscience laboratory settings cannot be applied to real-life contexts, including classrooms. Moreover, advanced neuroimaging technology has made possible the observation of the learning brain in near-natural states, perhaps steadily closing the distance between “neurons and neighborhoods”.

Equally unfounded is the skepticism around the applicability of neuroscience findings because they are micro-modular in scope while teaching and learning are complex and multifaceted. Generally, an understanding of complex systems demands iterations between deconstructing them into constituent micro- or even nano-elements, analyzing them in order to understand how each element functions, and synthesizing them back into complex systems. It entails the reconstruction of the elements to understand how they iterative-



ly interact to form a gestalt, and ultimately, complex processes like teaching and learning. It is not surprising that individual neuroscience research would lead to modular understandings of aspects of learning. The challenge is how to strengthen intradisciplinary and transdisciplinary collaboration to support the building of credible frameworks that enable the interlocking of scientifically grounded nano elements into gestalts that progressively approximate the complexity of teaching and learning. Such frameworks have to necessarily be based on forward and backward iterations of analyses and syntheses that are equally grounded in a holistic understanding of neuroscience, as well as of teaching and learning.

Howard-Jones et al. (2018) spoke to this challenge by noting that the SoL has lacked a framework for analyzing classroom practice that interrelates scientific insights from diverse sources with the day-to-day decisions made by a teacher. They illustrate the potential for a collection of scientific studies of “approach motivation” to shed light on classroom strategies for improving student engagement in educational contexts of which scientific understanding is still in its infancy.

The criticism that applications of neuroscientific knowledge to classrooms may promote neuromyths is easily dismissed because it has little to do with the research itself, and more to do with its misunderstanding and/or misuse. During the hype of the decade of the brain (1990–2000), scientifically unfounded and commercially driven interests propagated so-called brain-based education programs, brain-based curricula, guides to brain-based learning styles, and programs to boost brain power and make people smarter. These misuses tarnished credible efforts at applying neuroscience research to education practices. However, this could happen to any burgeoning field, but it should not detract from credible efforts to grow the field, and to apply it to teaching and learning.

Lastly and most importantly, as academic debates rage on, so does the global learning crisis. Regrettably, it is a crisis with unaffordable consequences, and one that can undermine individual, national, and global development. The potential contribution of neuroscience has to be unleashed, and tried and tested contributions applied to enrich teacher insights on effective facilitation of learning. These might involve the provision of scientific evidence for approaches that already work, thus boosting teacher confidence to further use and share them. It could entail new insights that enrich classroom practices and give every learner a winning chance at effective lifelong learning. Whatever the nature of the contribution, optimal use of every potential contribution to addressing the global learning crisis is urgent. More and collaborative efforts need to be made to foster the application of credible neuroscientific research findings to inform curriculum, teaching, learning, and assessment.

Fostering evidence-based facilitation of learning

In 2016, the IBE and the International Brain Research Organization (IBRO) launched an initiative to expand

the translation of credible neuroscientific research for application to education practices, particularly teaching and learning. The initiative entails a competitive fellowship that annually sponsors three to five senior neuroscience researchers to spend three months at the IBE doing translation work, and interacting closely with IBE’s senior educationists. By end of term, each senior fellow produces six succinct reader-friendly technical briefs that make vivid implications of neuroscience research findings for the IBE’s key areas of focus—curriculum, teaching, learning, and assessment. The briefs are globally disseminated through the IBE’s Science of Learning Portal: <http://ibelearning.wpengine.com>, and its blog, IBE Speaks.

The portal and the blog are buttressed by other dissemination channels including IBE-convened high-level dialogue between world-class neuroscience researchers and Ministers of Education and their senior policy experts, IBE web-news, social media, integration of technical briefs into the IBE’s accredited certificate, post-graduate diploma, and Masters degree courses, and technical assistance programs. A modularized curriculum is being developed for countries to include in their teacher pre- and in-service training programs. The curriculum should boost teachers’ neuroscientific understanding of human learning and improve their effectiveness as frontline facilitators of learning.

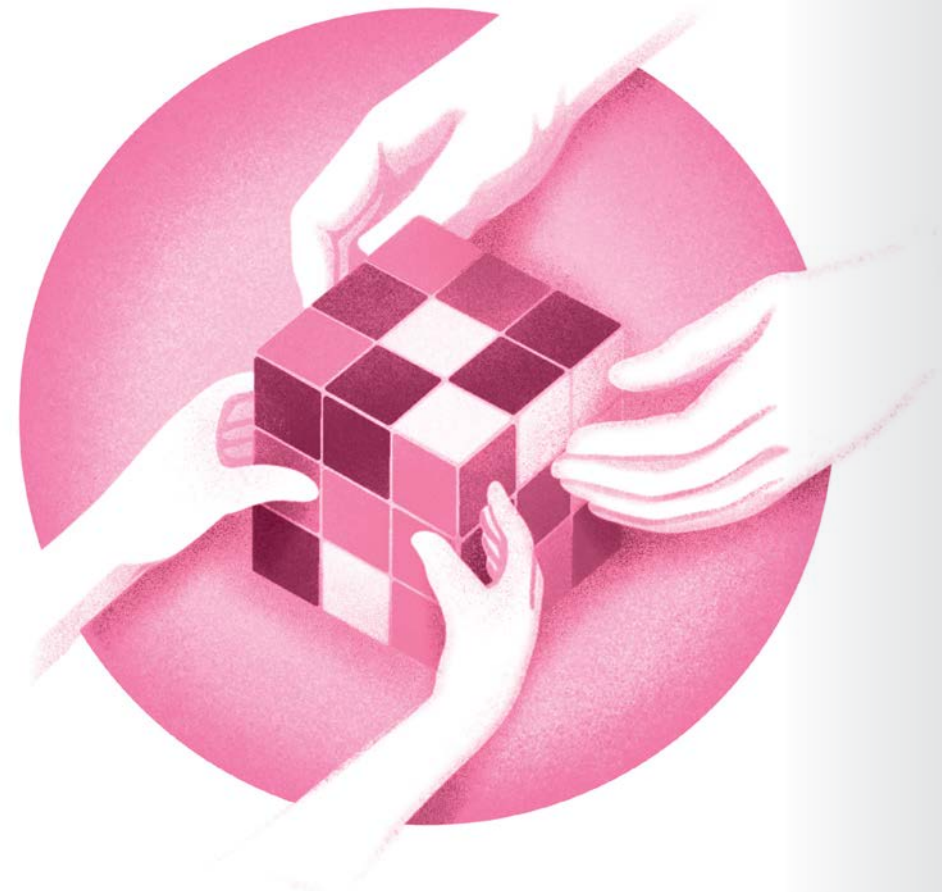
Since its inception, the initiative has attracted technical partnerships with SoL centers at some of the world’s most prestigious universities, including the following:

- *Institute for Learning and Brain Sciences, University of Washington, US;*
- *Queensland Brain Institute, University of Queensland, Australia;*
- *Technology-enhanced Learning in Science, University of California Berkeley, US;*
- *Université de Paris Descartes, France;*
- *Western University, Canada; and soon,*
- *Key Lab at Beijing Normal University, China;*
- *Cuban Neuroscience Center, Cuba;*
- *Universidad de la República, Uruguay;*
- *University of Cambridge, UK.*

Among other contributions, these partners deposit their own translation work to the IBE Science of Learning Portal, thus, expanding the volume and quality of work beyond the capacity of IBE alone.

The initiative proceeds on the premise that educators’ scientifically based understanding of learning is fundamental for transforming how they facilitate student learning. This is not to suggest that scientifi-

The IBE welcomes you:
Together let’s push back
decisively on the global
learning crisis.



cally based understanding of learning is a silver bullet. However, understanding how people learn should add significantly to teaching not just what to learn but most importantly, how to learn. In fast-changing 21st century contexts, knowing how to learn is the most profound competence (Marope, Griffin, and Gallagher, 2017). Effective lifelong learning is an indispensable source of agility to adapt and to stay relevant. By strengthening its contribution to effective facilitation of learning, neuroscience can contribute significantly to efforts to address the global learning crisis.

While further work is always necessary, the current base of credible neuroscientific research is under-exploited for purposes of informing effective facilitation of learning. More often than not, neuroscientists’ interaction with educators is for further knowledge creation rather than for knowledge application. Limited attention to translation work constrains the potential of science to transform education practices just as it transformed medical practices a century ago (UK Royal Society, 2011). By significantly expanding the volume and quality of translation work, the IBE/IBRO initiative unleashes the transformative potential of science on education and learning.

This translation work has difficulty reaching a large base of educators, especially those in the least developed countries and in disadvantaged contexts of developed countries. Yet, these are contexts where the global learning crisis is deepest, and where educators need insightful inputs from every credible source. Educators’ access to insights from neuroscience is constrained by the following factors:

Limited literal or physical access: Current translation work is mostly generated by university-associated SoLs across the developed world and in emerging economies across Asia and South America. Access beyond these key production points is very limited due to lack of awareness and/or limited connectivity to digital information sources.

Limited substantive access: Even where there is literal or physical access, the complex presentation of credible neuroscientific research findings combined with educators’ lack of exposure to the field creates a formidable barrier to substantive access. Another barrier to substantive access, in least developed countries and in disadvantaged areas, is that educators are generally ill-prepared for their regular work, and this grossly limits their capacity to seize opportunities to learn, especially from such complex fields as neuroscience.

Challenges of scaling up promising applications of neuroscientific knowledge: Invariably, classroom applications of translated neuroscientific knowledge is limited to schools within reach of key knowledge production centers. The small scale is dictated not only by the physical accessibility of collaborating schools, it is also in the nature of experimentation. Cross-country collaborative work is not uncommon, but it is still at a small scale. These collaborative applications are creating pockets of best practices and excellence on how neuroscience can transform the facilitation of learning at the school and classroom level. However, these are small and highly localized, which translates into limited dissemination and limited impact. Researchers lack the opportunity to rigorously test their applications in different contexts. Localization also sustains inequities of effective learning opportunities to the extent that the application of translated work has limited positive impact on teaching and learning, which undermines the intention of SDG4, and ultimately, other SDGs whose realization depends on quality education and effective lifelong learning for all.

Limited segue into global education policy and practice stream: Because of the limited geographical origin, limited dissemination, and limited testing across diverse contexts, translated work has no easy segue into national and global education policy and practice streams. This further limits the potential contribution of neuroscience to equity of effective learning opportunities.

The IBE/IBRO initiative addresses some of these key challenges. Through strategic technical partnerships, it expands the base and quality of the translation of neuroscience research findings for application to education practices with emphasis on teaching and learning. Multimedia are used to globally disseminate translated work, ensuring both literal and substantive access. Direct pre- and in-service training of teachers, as well as direct training of curriculum and assessment experts further consolidates substantive access to credible neuroscientific knowledge. These training programs open the way for scaling up the application of neuroscience to education practices.

Beyond teachers and other middle level educators, the IBE leverages its global convening power to foster dialogue between senior education policy makers and world class neuroscience researchers, thus opening channels for neuroscientific knowledge to enter the national and global education policy arenas. More collaborative work is needed to bolster effective facilitations of learning and to reverse the global learning crisis.

TECHNOLOGY

THE DOUBLE-EDGED SWORD

by

Conrad Hughes

AND EDUCATION

*In a world of rapid change and unknown
unknowns, the double-edged sword of technology
has to be wielded with care by educators, so that
it becomes a force for good.*

Rapid, disruptive cycles of change in many fields of human activity have been set in train by technology: the internet of things, biotechnological advances, robotics, and big data have come to be known as the 4th Industrial Revolution.

THE WORLD TODAY: RAPID CHANGE AND UNKNOWN UNKNOWNNS

We are in a paradigm of exponential change where the unknown unknowns of the future loom before us, making us question the way we look at the world and how we educate young people to thrive in it.

Technology plays a central role in driving change at an ever-increasing, dizzying speed: the world population has quadrupled since World War II (from 2 billion to nearly 8 billion people) thanks to technological advances in medicine; the speed at which we are destroying the Earth is accelerating (we are exhausting well over 160 per cent of the planet's biocapacity) because of rampant industrialization and technology-assisted overproduction; the concentration of power in the hands of fast-growing technology companies intensifies, while artificial intelligence now does stock market trading in micro-seconds, assisting multinationals in becoming massively powerful monopolies as they eat each other up.

This juggernaut of change creates different reactions in people: some look at it as a terrifying tornado spiralling closer and closer to a disastrous end, others view opportunity and access. Indeed, globalization, comparative

ease of travel, the sharing economy, and communication networks enhanced by social media have made the world far more accessible than ever before. Many diseases that plagued humanity for centuries have been eradicated and extreme poverty is less acute on a global scale than it was 30 years ago.

At the same time, growth in income disparity and new forms of terrorism have further divided the planet's population into separate enclaves, and extremist political views are again rearing their ugly heads, as many world leaders embrace xenophobic, protectionist, and segregationist beliefs, barring the gates of immigration that led to so much of the prosperity and opportunity in the Old World.

The world of today is one of VUCA (volatility, uncertainty, complexity, and ambiguity). It is also a world of paradox, for so much of what we see unfolding has positive and negative ramifications simultaneously: it is the age of the double-edged sword.



In each child there is the promise of the powerful, ethical, creative, critical, and engaged adult she or he will become.

WHAT IT MEANS TO BE AN EDUCATOR

At the centre of this technological whirlwind is the young person looking into the future.

In each child there is the promise of the powerful, ethical, creative, critical, and engaged adult she or he will become, not to mention the capacity she/he has to go further than our education systems allow right now. What a privilege to educate but what a responsibility, too. The decisions we take as instructors can help shape not only learners' confidence but also the way they act, for the future of humanity. Building an educational voyage is not just a question of technology, pedagogy, and curriculum, it is a question of human relationships.

We know enough today about the social and emotional brain not to fall into the trap of seeing education as a purely technical or rational exercise made up of short-cuts and tools. We understand, possibly better than ever before, that the psychodynamics of learning are fragile and subtle, and that they rely on the interpersonal dimensions of any relationship: trust, confidence, mutual respect, and shared passion. Teachers in the twenty-first century need to be domain specialists, facilitators of competences, and outstanding pedagogues

whose practice is informed by research. They also need to be caring, to seek feedback from learners, to be sensitive to the specific, contextualised social dynamics of the group, open to new ideas, and compassionate. All of this must come before any mention of technology, for technology is a means, not an end.

The double-edged sword of the world of VUCA implies polyphonic teaching, a dance with ambiguity allowing learners to take ownership of the learning process, without dumbing down the sacred transmission of powerful concepts that bind everything together. And the double-edged sword of technology has to be wielded with care in this dance, so that it becomes a force for good.

SEVEN STABLE MACRO-COMPETENCES



Lifelong learning
Curiosity
Creativity
Critical thinking



Self-agency
Initiative/Drive/Motivation
Endurance/Grit/Resilience
Responsibility



Interactively using diverse tools and resources
Impactful use of resources
Efficient use of resources
Responsible consumption



Interacting with others
Teamwork
Collaboration
Negotiation



Interacting in and with the world
Being local and global
Balancing rights with privileges
Balancing freedoms with respect



Trans-disciplinarity
STEM
Humanities
Social sciences



Multi-literateness
Reading & writing
Numeracy
Digital

The seven stable macro-competences, listed above in order of importance, entail several different adaptable micro-competences.

IBE'S SEVEN MACRO-COMPETENCES

As we approach the first quarter of the twenty-first century, schools, universities, industries and society at large are asking fundamental questions about education. Various frameworks map out educating for skills rather than knowledge alone, along with the importance of mindset, values and wellness. At the same time, there is an increasing worldwide emphasis on the importance of design thinking, creativity, empathy, and problem-solving.

Developed through in-depth forecast analysis by some of the world's most perspicacious thought leaders and academics, involving work with UNESCO Member States, the IBE's seven macro-competences make up the mother framework that not only subsumes all other frameworks, but organizes constituent elements in a taxonomy explaining relationships, disaggregating domains, and presenting an entire educational process.

The IBE-UNESCO model allows us to conceptualise the educational voyage from environmental elements ("constituents") through to application, as they are put in the service of developing the macro-competences, and, finally, to positive outcomes, as the model explains how this can create in-

dividual, collective, and societal impact for good.

Importantly, the macro-competences, which are stable and predictable for the foreseeable future, relate to micro-competences, which are more specifically defined according to context, and will change in emphasis and nature over time.

Artificial intelligence describes a machine-based pattern-recognition functionality that allows non-human constructs to perform higher-order human tasks such as interpretation of complex data, natural language recognition and production, complex task delivery, such as driving a car or playing games. A further and essential difference between artificial intelligence and simple computer programming is that the former entails what is called “machine learning”, in other words, a process whereby software gathers data on past operations, and synthesises and arranges the data to make predictions about future applications. This is very much the premise of the search engine, which is based on the hitherto exclusively human mental domains of association and comparison.

In some areas of human activity, lower-order functions of knowing and understanding, and even some higher-order thinking skills such as synthesis and inference-making, can effectively be done by software. However, we should not lose sight of the fact that the only possible premise for this type of computation is probabilistic and strictly data-driven; it is not harnessed from metaphysical entities that—at least for the time being—seem to be uniquely

human (emotions, belief systems, motivation, ethics, judgement, aesthetics, subjectivity, culture, existential decision-making).

The machines that humans have built and the algorithms that drive them are challenging the uniqueness of some of the essential constituents of human intelligence. Humans are increasingly attached to devices and dependent on them. The implications of artificial intelligence are that some areas of human activity can be outsourced to machines whereas others cannot. This leaves a space for schooling to develop those skills and attributes that are uniquely human and cannot be taken over by artificial intelligence. These include relationships, culture, empathy, higher-order thinking and happiness.

At the same time, schools need to equip students with the competences necessary to use tools interactively and effectively. Grappling with singularity involves enhancing the micro-competences of digital literacy and data literacy, while celebrating different types of collaboration (the macro-competences of interacting with others, interacting in the world, and interactively using diverse tools and resources).

The implications of artificial intelligence are that some areas of human activity can be outsourced to machines, whereas others cannot. This leaves a space for schooling to develop those skills and attributes that are uniquely human and cannot be taken over by artificial intelligence.



Central to the question of how to adapt education to the challenges of today’s world is how we use technology as an enhancer of learning. It is quite obvious that opportunities to differentiate instruction, to personalize learning, and to give access to information have been revolutionised by the World Wide Web.

Not only can students learn in online environments that allow teachers to assess the pace and progress of learning of each individual through a dashboard, they can find models, examples, other learners, and tutors online to help them better understand what they are learning. Massive open online courses (MOOCs) from the world’s best universities can be accessed, as can lectures and masterclasses by the world’s best instructors.

One must ask oneself what the purpose of lecturing is in today’s classroom, since any oral or face-to-face lecture can also be transmitted electronically. The so-called “flipped classroom”, where teachers concentrate on higher-order thinking, reflection, discussion, and Socratic dialogue in the classroom, while students watch films and do adaptive online assessments at home, seems like a natural pedagogy to endorse

as it takes advantage of technology and accelerates processes that used to be implemented by the teacher, such as talking through information, outsourcing it to a more efficient platform.

Given the ubiquity of technology in the workplace and the fact that it will remain a central expression of work in the future, even if we are not sure exactly what kind of work that will be, it seems meaningless to have students draw graphs with pencils, stick photocopied pages into workbooks, and carry heavy textbooks in their backpacks in the twenty-first century.

Technology has the ability to revolutionise access to learning and deconstruct schools to the point where one must question their purpose. Surely, students can access everything they need, anywhere, anytime, and without the need for a physical teacher? In some ways, schools actually appear to be holding up young people’s integration into the technologically advanced world of work in the twenty-first century by forcing them to learn in antiquated, irrelevant modes.

At the same time, we know more about the neuroscientific dimension of learning today than we ever did before. Learning occurs when human beings are stimulated emotionally so that their cognitive engagement is optimal. That level of stimulation needs to be carefully balanced between the limbic and the cortical lines of attention to ensure a “sweet spot” of concentration. Essentially, it requires human interaction.

Furthermore, we have known since Vygotsky that learning happens in a social context and needs not only an emotionally engaged instructor who connects personally with each learner, but a certain climate and culture among the group of learners. This is difficult to achieve in a virtual environment where people are interacting with each other through screens.

Studies have shown that handwriting is a better way of coding and storing information than typing, while basic elements of learning, such as interleaving, spaced repetition and deliberate practise, need a coach, a physical presence to guide students through the story of learning that is much more subtle and complex than simply accessing information. Information needs to be

coded, conceptualized, stored, and retrieved, and for this to be done well, a teacher is needed to help explain concepts, test them, engage students in exercises with one another and assess higher-order areas of cognition that algorithms struggle to accommodate, most online assessments being fairly wooden tools such as multiple choice tests. Interestingly, meta-analyses in education that show the correlations between innovations in the classroom and learning gains, such as those conducted by Hattie, Marzano, or the Sutton Trust, tend to feature technology quite low down, compared to uniquely human pedagogic skills such as direct instruction, mastery teaching, feedback, and collective teacher efficacy.

Clearly, a balance is needed, where the best elements of human interaction are coupled with the efficiency that technology allows: a classroom where passionate, cultivated, and highly competent teachers, who understand the importance of social psychology and cognitive psychology in learning, use cutting-edge platforms and tools to create engaging learning tasks and assessments.



A balance is needed where the best elements of human interaction are coupled with the efficiency that technology allows: a classroom where passionate, cultivated, and highly competent teachers, who understand the importance of social psychology and cognitive psychology in learning, use cutting-edge platforms and tools to create engaging learning tasks and assessments.

Central to the debate on technology in schools is the use of smartphones. Should schools allow them or ban them? Debates on the subject are heated with different approaches practiced across the globe. Some districts or curriculum boards ban them, whereas others embrace the use of all types of technology. The argument is essentially that, on the one hand, excessive smartphone use has been shown to reduce grey matter, working memory capacity and long-term concentration, while, on the other, the purpose of education should be to bring young people up in an environment that prepares them for the world and since the smartphone is ubiquitous in the modern world, these should be integrated into learning. Most schools have a restrictive approach, either partial or total.

Smartphone use is also an accelerator of social media use, which brings with it a number of issues, particularly cyberbullying, grooming, problems of self-esteem, and related anxiety. At the same time, social media allow for communities of learners to share ideas from different parts of the world, building up virtual communities of learners.

The use of technology in schools is thus a double-edged sword

that looks and feels different in each context, and there can be no oversimplified, blanket approach. Context and overall school culture need to be considered in order to decide what is best.

Many people in the modern world suffer from high levels of stress through hyperactive lifestyles that can become unhealthy and compulsive. Needless to say, the interference of new technologies in the average person’s life is a contributing factor that needs to be mediated sensibly. This has led to a number of responses, especially in schools, in the area of mindfulness.

While new-age attempts to spiritualize life through meditative practice are effective, other avenues that can lead to a mindful lifestyle are actually fairly simple and have been embedded in school programmes for years. Intense physical and artistic activity, drawing a learner’s entire being into a “zone” of concentration and a “flow” of seamless process, can very well have the effect of allowing the mind to gain focus and stress levels to drop. This is one of the reasons why all schools should continue to have strong arts and sports programmes. Mindfulness can be achieved if we help learners concentrate on developing their health and wellbeing. This also implies moments away from technology, when the lure of social media, the pixels of the computer screen, and the open laptop are discarded for learning experiences that are kinaesthetic.

The way that most of us use the internet in today’s world is to confirm bias: we seek confirmation of our beliefs and, with the amount of information circulating on the Web, there is a strong chance we will find it. This way of conducting research does not put the idea of truth and the exposure of falsehood at the centre of knowledge, leading to a process that is not intellectually rigorous or even necessarily honest.

Political developments, especially in the US and the UK, in the middle of the first quarter of the twenty-first century have led some to argue that truth does not mean what it used to, that we are entering a type of post-truth era, where communication strategies supersede the verity of what is being discussed.

We should be careful about how we grapple with information nowadays: there are approaches to knowledge construction that are essential in an age of sound bites and alternative, often false positions broadcast on social media. To be an informed critical thinker in the twenty-first century means to be a lifelong learner, the macro-competence that includes an attitude of humility and acceptance that we might be wrong. Another essential mac-

ro-competence to develop in this vein is multi-literateness, for, without truly mastering a domain, how can we ever be in a position to question it?



Intense physical and artistic activity, drawing a learner’s entire being into a “zone” of concentration and a “flow” of seamless process can very well have the effect of allowing the mind to gain focus and stress levels to drop.

Because of new technologies and the way that knowledge is made available and distributed, some believe that we need to rethink what is taught in school entirely and perhaps teach less content, opening more time and opportunities for skills development. This debate has grown more and more acute.

While it is true that information is readily available through a simple smartphone with an internet connection, it is dangerous to imagine that we need to know less, for knowledge is a foundational building block of critical thinking, culture, and understanding. Students need to have historical, scientific, geographic, cultural, and artistic sensitivities to appreciate the world around them and defend a point of view. At the same time, they need to master languages and numeracy for those sets of knowledge to be readily available from long-term memory to apply fluidly in new circumstances.



Students need an environment where physical activity, artistic exploration, interpersonal skills development, and deep thinking are complemented by the use of new technologies, when and where appropriate, to accelerate learning and make it more powerful.

CONCLUSION

The age of artificial intelligence threatens not only routine labour but many white-collar jobs too. Algorithms are already seen as far more reliable than human lawyers, doctors, and life-coaches. Educational practice needs to place greater emphasis on higher-order thinking such as analysis, synthesis, evaluation, and creativity. One might add to these areas of thinking those non-outsourcable dimensions of human behaviour that involve ethics and values.

A number of strictly cognitive higher-order operations can be simulated and perhaps even transcended by algorithms, especially those that deal with logico-mathematical intelligence involving multivariate analysis, deduction and statistically-based predictions based on hard data. This does not mean that these skills will no longer be harnessed in schools but that they should be developed alongside what algorithms can already do. By learning alongside powerful software instead of spending time on what software can do already, students' logical higher-order thinking can be driven to practical and creative applications of information or to modulate creative scenarios according to different contexts. For example, rather than



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asking geography students to go outside and count the number of cars that drive along a road, they can access this information—or similar information—through a quick computerized search and then spend more time guessing and debating what the traffic flow might be like in different contexts (good or bad weather, weekend or week, whether there were more or fewer public transport links covering the same route, or more or fewer schools and businesses in the vicinity).

Therefore, educating for higher-order thinking should be considered in the context of the rapidly expanding computational power, design acceleration, and automation that science, technology, engineering, and mathematics (STEM) can produce. Many processes involved in project development and in learning itself can be automated in line with Bloom's taxonomy. For example, students can accelerate lower-order routines by using search engines to access references and key information quickly so as to spend more time and energy on synthesising; hand-plotting graphs does not seem necessary in an age of graph-plotting software; data gathering for subjects such as geography can be automated, allowing more time for pattern detec-

tion and analysis, while general knowledge and understanding in a number of subjects can be tested through random item selecting software.

A word of caution, though: students still need to learn and develop a strong basis of academic knowledge. In order to activate these higher-order thinking skills, they will need to read long, detailed, and well-written texts, learn historical facts, and master many concepts.

On the other hand, because automatable thinking skills are reaching higher rungs of cognitive architecture with software capable of driving stock-market decisions, medical analyses, or legal opinion, schools need to focus on facets of being that are dispositional, teaching not only social intelligence but ethical decision-making, entrepreneurship, and innovation. Most schools claim to do this in one form or the other, but how many have the courage to insert into their actual curriculum, formal assessment, and timetabling the learning experiences that will allow these competences to flourish? Most national curricula are made up of academic subjects, high-stakes examination preparation, content testing, and a strong culture

of grading, but do not deliberately and openly assess character or take students off timetable to work on macro-competences such as lifelong learning or self-agency, interacting with the world or interacting with others. One programme that does this is the International School of Geneva's Universal Learning Programme, developed in conjunction with the IBE.

All in all, a balanced approach is needed, one that allows access to technology but also protects students from too much technology; an environment where physical activity, artistic exploration, interpersonal skills development, and deep thinking are complemented by the use of new technologies, when and where appropriate, to accelerate and make learning more powerful. Technology is a double-edged sword, it always has been. May it be handled with care.



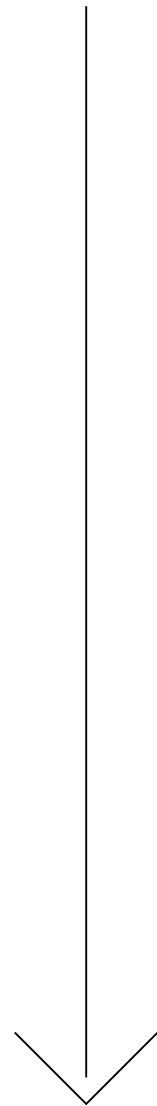
Applying the Science of Learning

→ to Education

TWO
STRUCTURAL
REQUIREMENTS

by
Daniel Ansari

How do we



learn?

How does learning change over the lifespan? What cultural and biological mechanisms underpin learning? How can learning be fostered in formal and informal educational contexts?

Answers to such fundamental questions require collaboration between researchers from different fields, such as Education, Psychology, Neuroscience, and Cognitive Neuroscience (Meltzoff, Kuril, Movellan, and Sejnowski, 2009).

Over the past three decades, a new, interdisciplinary field referred to as the “Science of Learning” has gained increasing traction across the globe. At the beginning of the 21st century, the US National Science Foundation invested in six “Science of Learning Centers” across the US. Since then, Science of Learning initiatives have sprung up across the globe.

While it is abundantly clear that there is great enthusiasm for the Science of Learning, there is still a significant gap between the latest research on how we learn and the application of that research to teaching and learning across the lifespan. Why does this research-application gap persist despite significant global enthusiasm and research funding?

Some of the reasons may be philosophical in nature, such as resistance to the application of empirical research to human development and learning (Cohen and Lagemann, 2007). I contend that the main obstacles to the application of the Science of Learning are practical in nature and require new educational policies. In what follows, I discuss two structural issues that need to be addressed urgently by educational policy makers in order to facilitate the impact of the Science of Learning on learning and education across the lifespan.



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The Science of Learning needs to be part of pre- and in-service teacher training.

At present, the Science of Learning is not something that is systematically covered in teacher training programs across the world. Teacher training programs may cover some aspects of human development and developmental psychology, but these, in my experience, tend to be, at best, outdated and, at worst, fundamentally wrong. I frequently hear from teachers that the only exposure they had to cognitive development research in their training was a brief discussion of the work of Jean Piaget. While Piaget’s contribution to our understanding of how children acquire knowledge is immense and foundational, it is also clear that our understanding of human development has changed significantly since Piaget and many of his theories have been questioned by more recent evidence.

Currently, pre- and in-service teachers are only exposed to the Science of Learning by chance, or if they actively seek it out in their own time. In my view, this is problematic. Why are teacher education programs depriving future teachers of knowledge that could inform their practice? In order for research in the Science of Learning to have an impact on education, educators

need to have the opportunity to learn about it and reflect on how they may apply it to their practice from the start. Therefore, it is necessary for teacher training programs to include courses (or units within existing courses) that cover research on how children learn to read, write, calculate, and interact with others in the world around them. Such knowledge would help teachers understand, for example, why systematic phonics instruction is so critical for young readers (Castles, Rastle, and Nation, 2018) or why it is critical for children to learn numerical symbols (Merkley and Ansari, 2016). For in-service teachers, opportunities to enact principles derived from the Science of Learning in their own classrooms should be provided.

Beyond learning about principles from the Science of Learning, teachers deserve to have some training in how to evaluate whether popular claims about how children learn and should (or should not) be taught are evidence-informed. This requires some basic training in the scientific method and how to determine whether a particular educational claim or product has been informed by scientific evidence.

Some argue that the Science of Learning is not directly applicable pedagogy. In other words, learning about the Science of Learning does not tell teachers how to teach. In my opinion, this view reflects a very narrow conceptualization of teachers and effective education. According to this view, teachers are there to execute a curriculum and do not have any choice or agency when it comes to the way they teach. While this may be true in some jurisdictions, this is certainly not the case in many educational systems around the world where teachers have autonomy (within constraints) and need to make choices about how to teach.

Should these choices not be informed by what we know from empirical research regarding how humans learn? Research into the cognitive mechanisms that underpin human learning has revealed many principles that are directly applicable to education. For example, new studies challenge the view propagated by Piaget and others that discovery learning is superior in all contexts (Dean and Kuhn, 2007; Klahr and Nigam, 2004). There are many other examples of principles of learning and teaching that have been well-supported by empirical evidence from the

Memory

Science of Learning (Weinstein, Madan, and Sumeracki, 2018).

A way of demonstrating the importance of integrating the Science of Learning into teacher preparation and in-service teacher professional development is to consider the known consequences of not doing so. For example, teachers (including those who become administrators in their boards and schools and have decision-making authority) who are not exposed to the Science of Learning are not sufficiently informed to evaluate the veracity of claims about how children learn. Neither are they equipped to evaluate whether the latest educational program that their school has adopted is actually effective.

This state of affairs has detrimental consequences. Consider the recent hype around working memory training (working memory refers to the ability to hold information in mind while carrying out another task). Many schools around the globe purchase programs that claim to train the working memory of students with difficulties (such as those with Attention Deficit Hyperactivity Disorder; ADHD). Critically, these programs claim that if students train their working

memory their overall learning will be improved. In other words, following training, students will not only have improved working memory but also improve their academic achievement in, for example, math and reading. This promise is, of course, very attractive and offers a simple solution to a complex problem.

Alas, simple solutions to complex problems are most often too good to be true. A large body of research has shown that working memory training does not lead to the kind of outcomes that have been promised. Large-scale studies have shown that while training with working memory games makes students better at those games, such training does not improve their learning of other subjects (Melby-Lervåg and Hulme, 2013; Simons et al., 2016). Yet, money is still being wasted, on programs, such as working memory training. This represents a clear example of how not having training in evaluating programs and the evidence that underpins them leads to wasteful use of funds and ineffective use of instructional time.

It is well established that many educators across the globe hold beliefs about learning and education that have been proven to be

unsupported by evidence (e.g., Howard-Jones, 2014). Sometimes such claims are referred to as “neuromyths” and include false claims about some students being more “left-brained” while others are more “right brained”. Another example is the notion that students differ in terms of their so-called “learning styles”. According to the learning styles theory, some students are better at learning information when it is presented in their preferred modality for learning, including visually, verbally, or kinaesthetically. Learning styles can be found in many educational materials and even curricula, yet empirical research in the Science of Learning has conclusively shown that: a) the assessment of learning styles; and b) the tailoring of instruction to learning styles are not effective; and c) the concept itself is not consistent with the Science of Learning (Pashler, McDaniel, Rohrer, and Bjork, 2009; Willingham, Hughes, and Dobolyi, 2015).



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Teachers | —————> students

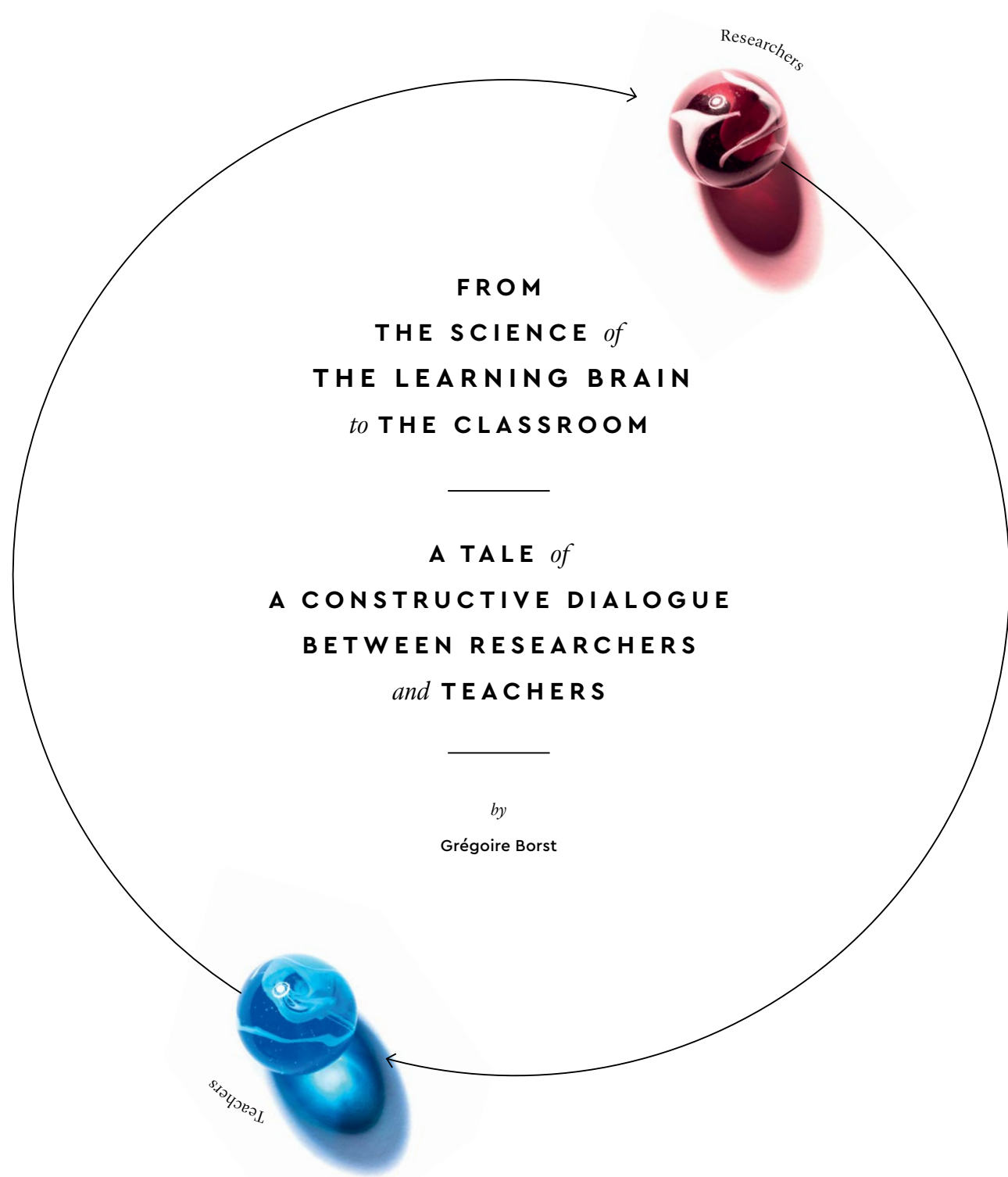
It will not be enough simply to train pre- and in-service teachers in the Science of Learning and how to apply it to their practice. We cannot expect teachers to become researchers. We should not develop policies that take teachers away from working with their students. Thus, in addition to the changes in teacher training discussed above, there is a pressing need for individuals that have crossed the research-education divide to be accessible to classroom teachers and, most critically, to understand the position of classroom teachers. In a perfect world, each school district/board/division should have at least one individual who was a) trained to be a teacher; b) has had experience teaching; and c) has been trained (at least to the Masters level) in the Science of Learning (broadly defined). Such individuals will be ideal translators between research and practice. Their role will be a) to help teachers and administrative leaders select teaching and assessment approaches that are grounded in the Science of Learning; b) to help teachers and administrators to make evidence-informed decisions; and c) to vet the evidence base of programs that schools are considering adopting.

Imagine a world in which teachers can access such “Science of Learning Translators”. A teacher being confronted with a claim about how children learn or a product that promises to advance students will be able to consult with such translators. I predict that the effects of this would be tremendous. Teachers would be able to speak to somebody who fully understands their role, their constraints, their struggles and, simultaneously, be able to consult them on what is evidence-informed and what is not. Beyond teacher-driven consultation, such individuals would also be able to suggest evidence-informed approaches to teachers. Furthermore, beyond single individuals, one could imagine “Science of Learning Translators” forming networks to provide advice and knowledge translation that would be greater than the sum of its parts.

The Science of Learning is a growing interdisciplinary field across the globe. For it to truly have an impact on education systems, structural changes of the kind I have described above are sorely needed.



It will not be enough simply to train pre- and in-service teachers in the Science of Learning and how to apply it to their practice. We cannot expect teachers to become researchers. We should not develop policies that take teachers away from working with their students.



The science of the learning brain could shape the future of teaching and learning, but it would only do so if findings are effectively disseminated and there is genuine collaboration between the laboratory and the classroom.

Our societies are changing at an unprecedented rate due to the emergence of new technologies, driven in part by the digital revolution and social media. The social, cognitive, and emotional competences needed to thrive in society or in the workplace will dramatically change, and education needs to be reinvented to help children face the future. Paradoxically, in some education systems, learners are still taught using approaches from past centuries; manipulating the entry of information (i.e., the curricula) and examining its output (i.e., national or international evaluation such as PISA), with limited consideration of learning processes. This approach ignores growing evidence of how the brain develops, how it is shaped by cultural learning (reading, counting, writing, and reasoning) and how learning can be improved by taking into account the way the brain works. Progress in developmental, social, cognitive psychology and neuroscience should help shape the future of education by supporting the design of pedagogies that are informed by the science of the learning brain.

One of the key challenges ahead is to foster a continuing and non-dogmatic dialogue between researchers and teachers, to disseminate knowledge regarding the learning brain to teachers, students, and their parents. It is important also to develop collaborative and participative research to promote innovative pedagogies and to evaluate their effect on a large scale. The Laboratory for the Psychology of Child Development and Education (LaPsyDÉ) at the French National Centre for Scientific Research (CNRS), University Paris Descartes, has dedicated 15 years to the development of such innovative pedagogies, their evaluation, and the scaling up of their impact. Let me explain how we did it, and where we are now!

The process started with the creation of professional development groups in which researchers from our lab and teachers, who had been given time out of their classrooms by their school district, could meet and discuss some of the common learning problems students face in various academic areas.

Teachers were given the opportunity to understand the basics of the brain, including the process of maturation and how certain childhood and adolescent stages constitute sensitive periods for learning, due to the high plasticity of the brain at both the functional level (i.e., the networks of neurons activated during the resolution of a problem) and the structural level (i.e., the thickness of the external layer of the brain and the connections between the different brain areas). Teachers also gained a basic understanding of how the brain deals with the acquisition of cultural tools at school and in society (language, reading skills, mathematics, logical thinking, and critical thinking) and how new technologies and digital media, in particular, can be used to aid the acquisition of these tools by the brain during childhood and adolescence. Throughout, it was emphasized that the learning brain is both universal and very unique, which is consistent with what teachers experience in their classroom with students learning at different rates, using different strategies. For instance, evidence shows that individual differences in the shape of the small valleys (sulci) of the brain, which are determined early in life, can explain, years later, individual differences in the acquisition of cultural tools such as reading (Borst, Cachia, Tissier, Ahr, Simon, and Houdé, 2016).

Researchers are offered an insight into the common errors teachers, as key pedagogues and expert observers of student learning challenges in classroom settings, observe.

For instance, our research provides convergent evidence that some of the common difficulties students encounter in learning mathematics, literacy, or science could be rooted in the automatisms constructed in previous years of schooling (Borst, Cachia, Tissier, Ahr, Simon, and Houdé, 2016). Take, for example, the resolution of arithmetic word problems such as “Jeanne has 10 marbles. She has 5 more marbles than Billie. How many marbles does Billie have?”. This problem seems rather simple to solve. Except, when first introduced to it, students have a tendency to answer that Billie has 15 marbles because they are misled by the wording of the problem; it is unusual for the word “more” to be used in a way that is not associated with an addition.

Research demonstrates that overcoming these types of errors depends on the students’ ability to resist the automatism “add if more”, which has been reinforced in previous years of schooling (Lubin, Vidal, Lanoë, Houdé, and Borst, 2013). A similar type of error can be found when students first compare decimal numbers and conclude that 1.5 is smaller than 1.452, because they have a hard time resisting overgeneralizing the properties of whole numbers, such as “more digits, greater number”, to rational numbers (Roell, Viarouge, Houdé, and Borst, 2019).

These are important findings for teachers because they suggest that students’ errors, in contexts such as the ones presented above, reflect a specific difficulty in resisting automatisms constructed at school or in their daily environment and not a lack of knowledge. Helping students overcome such difficulties might then involve a different type of pedagogical intervention, rather than repeating the proper rule to use in such contexts. Research evidence shows that a meta-cognitive pedagogical in-



Take, for example, the resolution of arithmetic word problems such as “Jeanne has 10 marbles. She has 5 more marbles than Billie. How many marbles does Billie have?”. This problem seems rather simple to solve. Yet, when first introduced to this problem, students have a tendency to answer that Billie has 15 marbles because they are misled by the wording of the problem; normally “more” is associated with addition.



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tervention based on identifying the misleading automatisms that lead to errors in such contexts is actually more efficient (Houdé and Tzourio-Mazoyer, 2003).

So far, findings have been based on small-scale interventions, working with neighborhood schools. A key challenge, as always, is to scale up findings to a national or global scale, considering that such findings are potentially global public goods. This may require the extension of partnerships between researchers and teachers, to other actors with a wider footprint, e.g., private companies, ministries of education, or international institutions.

To scale up the intervention, we partnered with one of France’s major textbook publishers to access their platform, which hosts to a pedagogical and social network of more than 100,000 teachers. A virtual lab was designed on this platform to develop and promote collaborative and participative research with teachers in their classrooms.

In the first year of the project, a live online video-conference on the learning brain was organized for students. More than 4,000 students from preschool to middle school followed the conference and asked more than 800 questions, all of which were replied to within a few weeks. Teachers then identified common errors that could be related to a difficulty of resisting automatisms acquired in previous years of schooling, and evaluated their frequency. In the 150 classes from preschool to Grade 5 that participated, teachers reported more than 74 instances of this type of systematic error. Finally, teachers ran a randomized control trial, creating a control and an experimental group in their classroom, with objective evaluation pre- and post-training, to assess whether small daily activities in the classroom such as “Wesley says...” (an activity in which children execute an action but only when they hear “Wesley says...”) or “Stop and Go” (where children move towards the instructor when his/her back is turned, but must stop when they turn around) could improve the ability of their students to resist automatism.

The study was conducted in more than 115 classes with 2,800 students, without any intervention from researchers. They merely provided the material, the principle of the randomized controlled trial, and analysed the data collected by the teachers. Preliminary findings showed that the ability to resist automatisms did improve from pre- to post-training in the experimental group, as compared to the control groups who performed games that did not promote the specific ability. With this proof of concept, the second year of the project looks promising: more than 130 classes and 3,000 students are taking part in a follow-up study. This participative and collaborative project provides evidence that the experimental method can be successful in the classroom and can potentially be used by the teachers themselves to evaluate their pedagogical interventions.

Changing education in the twenty-first century will require continuous effort to bridge the gap between the laboratory and the classroom, between researchers and teachers, and between teachers and parents, to promote collaborative and participative projects that allow each of the key players to benefit from the expertise of the others, with the participation of national governments, international agencies, such as IBE-UNESCO, and private companies.

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In Focus

is an annual magazine published by UNESCO International Bureau of Education (IBE-UNESCO).

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