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Physiology and assessment as low-hanging fruit for education overhaul

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Abstract Physiology and assessment constitute major bottlenecks of school learning among students with low socioeconomic status. The limited resources and household overcrowding typical of poverty produce deficits in nutrition, sleep, and exercise that strongly hinder physiology and hence learning. Likewise, overcrowded classrooms hamper the assessment of individual learning with enough temporal resolution to make individual interventions effective. Computational measurements of learning offer hope for low-cost, fast, scalable, and yet personalized academic evaluation. Improvement of school schedules by reducing lecture time in favor of naps, exercise, meals, and frequent automated assessments of individual performance is an easily achievable goal for education.

Keywords Sleep · Nutrition · Exercise · Assessment · Learning

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Governmental, economic, political, academic, and religious agents agree that the solution for the major social problems of the world lies in the improvement and dissemination of education. Unfortunately, however, schooling is still of very low quality in most developing countries and faulty even in some wealthy countries (UNESCO 2011; OECD 2014, 2016).

Schools in communities with low socioeconomic status (SES) suffer academic deficits both when teaching occurs and when learning is assessed. Low-income families most often cannot provide adequate sleep, nutrition, or exercise to their members. According to the United Nations Human Settlements Programme (UN-HABITAT), over one billion people around the world inhabit slums (UN-HABITAT 2007), and by 2030 this number is likely to double (UN-HABITAT 2003).

Material and cultural poverty make evident that biology precedes psychology in school learning. Furthermore, schools in low-income communities typically cannot compensate for these problems, due to budget underfunding, classroom overcrowding, and underpaid staff. For the same reasons, schools most often fail to provide personalized attention to the students.

We propose that major improvement of schooling in the developing world, as well as in underdeveloped areas within the wealthy nations, can result from a school-centered reorganization of activities so as to overcome the physiological bottlenecks that hamper the health of children, derived from biological deficits due to inadequate sleep, nutrition, and exercise (Sigman, Peña, Goldin, and Ribeiro 2014). We also argue that computational tracking of students' learning-related verbal and written expressions may provide scalable, fast, low-cost solutions to improve individualized assessment of education outcomes in low-SES communities.

Sleep

In the U.S., nearly 30% of the adult population suffers from insufficient sleep (CDC 2013). Sleep problems are associated to obesity (Gupta, Mueller, Chan, and Meininger 2002; Knutson 2011; Jarrin, McGrath, and Drake 2013), poor nutrition (Beebe, Simon, Summer, Hemmer, Strotman, and Dolan 2013; Grandner, Jackson, Gerstner, and Knutson 2013; Hogenkamp et al. 2013), and increased cardiovascular risk (Buxton and Marcelli 2010). A cross-sectional study of 1101 Brazilian adult subjects (20–80 years old) found a depression prevalence of 10.9% and was significantly higher among housewives, unemployed individuals, and those with low income and education (Castro et al. 2013).

Decreased duration and quality of sleep may mediate the negative impact on health due to socioeconomic disadvantage (Van Cauter and Spiegel 1999). The invention of electric light and then of a myriad of electro-electronic devices has led to a substantial decrease in sleep time around the world. Average sleep duration is estimated to have dropped from 9 h in 1910 to 7.5 h just 65 years later (Webb and Agnew 1975). Artificial light has effects that superimpose on those produced by the natural light–dark cycle, possibly causing a misalignment of the circadian rhythms. Researchers investigated the effects on sleep—related to having or not having electricity—in 37 Brazilian adolescents (11–16 years old) using actigraphy for 5 consecutive days. Students without electricity at home showed significantly earlier sleep onset on school days (Peixoto et al. 2009). A study of 340 adult rubber tappers living in a remote region of the Amazon rainforest, most of whom had no electricity at home, found that the availability of electric light was associated with delayed melatonin increase, delayed sleep onset, and reduced sleep duration during workdays (Moreno et al. 2015). Not surprisingly, the daily schedule of activities has a major impact on sleep quality. A study of Brazilian medical students ($n = 27$), positively correlated later class-start times with better sleep quality and longer sleep duration (Lima, Medeiros, and Araujo 2002).

How are sleep problems related to living under social and physical stress in low-SES communities? A longitudinal survey of 11,838 adolescents (10–18 years old) found that hopelessness and exposure to violence produce negative independent and multiplicative impacts on adolescent sleep, particularly for females (Umlauf, Bolland, Bolland, Tomek, and Bolland 2015). To investigate how SES affects sleep habits in U.S. preschoolers, researchers assessed 3217 children ($\sim$3 years old) for the presence, time, and consistency of bedtime routines. Their study associated low maternal education, overcrowded household, and poverty with worse bedtime routines (Hale, Berger, LeBourgeois, and Brooks-Gunn 2009).

Sleep reduction is much more pronounced for low-SES individuals, reaching as low as 3.8 h in some occupations (Bliwise 1996; Bonnet and Arand 1995; Broman, Lundh, and Hetta 1996; Mitler, Miller, Lipsitz, Walsh, and Wylie 1997). The adverse conditions that lead to sleep problems comprise an unsafe environment, overcrowded sleep rooms, uncomfortable housing conditions (temperature, sound, etc.), as well as stress and anxiety. A longitudinal cohort study of 1405 Finish adults in the 1980s and 1990s showed that sleep quality was somewhat preserved during the severe economic recession of the 1990s, except in the case of low-SES unemployed individuals, who showed more insomnia, use of hypnotics, and other signs of decreased sleep quality (Hyyppa, Kronholm, and Alanen 1997).

Investigators looked at the relationship between sleep problems and academic achievement in 280 students (8–10 years old) from U.S. public schools. They assessed sleep with actigraphy during 7 consecutive nights, measuring sleep efficiency as the percentage of epochs scored as "sleep" between sleep onset and offset. The study highly correlated intelligence and academic achievement across a wide span of sleep quality, but in highly intelligent children this correlation decreased with low sleep efficiency, or fewer sleep episodes with long duration (Erath, Tu, Buckhalt, and El-Sheikh 2015). This result suggests that sleep problems may hinder the academic potential of even the most intelligent children.

For all we know, the mechanisms linking low SES to bad academic performance may be the same that connect low SES to poor health. Typically, low-SES families inhabit small and overcrowded residences in which beds are shared, and sleep quality is repetitively disturbed due to differences in work and school schedules among family members. An investigation of 1504 adults in the United States assessed the relationship between perceived neighborhood disorder and psychological distress. As expected, participants associated neighborhoods perceived as noisy, crime-ridden, and unclean with lower sleep quality and greater psychological distress, possibly as a causal chain of events (Hill, Burdette, and Hale 2009). A study of 170 pregnant women associated a household income of less than $50,000/year with reduced sleep quality and more sleep fragmentation, even after statistical adjustments for covariates (Okun, Tolge, and Hall 2014). Sharing the household with many individuals, particularly bed sharing, exposes children to sleep disturbances and anxiety due to noise, movement, uncleanliness, and other factors, which jointly have a negative impact on cognition (Liu, Liu, and Wang 2003; Solari and Mare 2012).

Many studies show that these conditions increase the number of nighttime awakenings, decrease total sleep time, and produce chronic sleep debt. An investigation of 371 adult, low-SES Latino residents of New York City revealed an association between home crowding and reduced sleep duration. Poor sleep quality, with more arousals and longer sleep latency, was associated with neighborhood disorder and perceived building problems—with compounded effects of negative housing and neighborhood conditions on sleep outcomes (Chambers, Pichardo, and Rosenbaum 2014). A representative cross-sectional survey of 8578 British subjects, ages 16–74, found strong independent connections between sleep problems and four SES indices: household income, educational qualifications, living in rented housing, and being unemployed (Arber, Bote, and Meadows 2009). An observational study of 150 adult slum dwellers from Buenos Aires, Argentina, before and after relocation to better housing, showed very positive effects of housing upgrading on sleep quality and quality of life (Simonelli et al. 2013).

Sleep problems during adolescence impact negatively on emotional balance and self-regulation, increasing the chance of risky behaviours. Using actigraphy, daily diaries, and questionnaires, a study evaluated 250 U.S. public high school students (mean age: 15.7 years) for sleep problems; these students were of low or middle SES (Matthews, Hall, and Dahl 2014). Most students showed less sleep than the 8–9 h recommended by the Centers for Disease Control and Prevention. Black students and male students showed less sleep, with more fragmentation. Female students reported worse quality of sleep and more daytime sleepiness. Results were significant even after adjustments for age, body mass index, physical activity, and smoking status. Black male students showed the least amount of sleep, which the authors hypothesized could be related to the increased risks suffered by this cohort (Matthews, Hall, and Dahl 2014). A recent large-scale cross-sectional study of 20,222 undergraduate students from 27 universities in 26 low- or middle-income countries across the Americas, Africa, and Asia showed that 10.4% of the subjects reported major sleeping problems, with a wide variation (3.0–32.9%) among countries (Peltzer and Pengpid 2015).

A very large-scale cross-sectional study of sleep problems using questionnaires was carried out with 43,935 subjects (above 50 years old) from 8 low-income countries from Africa and Asia: Ghana, Tanzania, South Africa, India, Bangladesh, Vietnam, Indonesia, and Kenya (Stranges et al. 2012). Severe or extreme sleep problems afflicted 16.6% of the subjects, with large variation across countries (from 3.9% in Indonesia and Kenya to 40.0% in Bangladesh). The study found a consistent association of higher prevalence of sleep problems with lower education, not living in partnership, and low quality of life. It revealed independent correlations of sleep problems with limited physical functionality/greater disability, and feelings of depression or anxiety (Stranges et al. 2012).

The social component can directly affect sleep deficits, because low-SES children often must work to supplement the household income. An investigation of how work affects sleep among adolescents (14–18 years old) found that working students ($n = 16$) woke up earlier than nonworking students ($n = 11$) on regular working days, causing a significant decrease in total nocturnal sleep duration (Teixeira et al. 2004). It found that SES negatively correlates with health outcomes, leading to a health gradient across SES strata (Teixeira et al. 2004). To examine whether a socioeconomic gradient also exists for sleep features, another study assessed 239 Canadian children and adolescents (8–17 years old) through self and parent reports. Several sleep measures showed socioeconomic gradients. Evidence associated objective parental SES with sleep disturbances and subjective SES with sleep quality and daytime sleepiness (Jarrin, McGrath, and Quon 2014).

In terms of mechanisms, it is no exaggeration to say that sleep deprivation impedes learning. Laboratory studies clearly indicate that sleep plays a crucial role both before and after the formation of new memories (Diekelmann and Born 2010; Mander, Santhanam, Saletin, and Walker 2011; Stickgold 2005). The large body of evidence pointing to the cognitive role of sleep has begun to motivate research in classrooms on the value of naps in school learning. An investigation of the effect of classroom naps on spatial learning by preschool children (n = 40, 36–67 months of age) showed nap-related gains 24 h after learning (Kurdziel, Duclos, and Spencer 2013). We have recently demonstrated the beneficial effect of naps for the retention of declarative memories acquired in school (Lemos, Weissheimer, and Ribeiro 2014). A total of 584 children in the sixth grade (10–15 years old) received a trial lesson and then were randomly assigned to continue awake or go to sleep for up to 2 h. To assess learning, researchers gave surprise tests days or months after class. The results showed very similar memory retention across sleep and wake groups when the evaluation took place 24 h after class. However, 5 days after the class, only the sleep group retained the cognitive gains. These results suggest that post-class naps can increase the duration of the memories acquired in the school setting (Lemos, Weissheimer, and Ribeiro 2014).

Further research must elucidate how to best use naps to aid learning. In particular, it is key to parametrize the cognitive effects of nap duration, sleep-state composition of the nap, and interactions with exercise and nutrition.

Nutrition

Food insecurity is associated with diabetes (Ding, Wilson, Garza, and Zizza 2014; Seligman, Bindman, Vittinghoff, Kanaya, and Kushel 2007), obesity (Tayie and Zizza 2009), hypertension (Seligman, Laraia, and Kushel 2010), heart disease (Seligman, Laraia, and Kushel 2010), hyperlipidemia (Seligman, Laraia, and Kushel 2010; Tayie and Zizza 2009), mental illness (Casey et al. 2004; Laraia, Siega-Riz, Gundersen, and Dole 2006), and depression (Seligman, Laraia, and Kushel 2010; Whitaker, Phillips, and Orzol 2006). A study of U.S. children and teenagers (6–16 years old) found negative psychosocial and academic outcomes associated with food scarcity (Alaimo, Olson, and Frongillo 2001).

It should not be any surprise that nutritional state plays a preponderant role in learning. The brain consumes about 60% of the glucose used up by the body. After a career testing substances that can enhance learning in humans and animal models, neurobiologist Paul Gold and colleagues found that one of the most effective is precisely glucose (Gold and Korol 2012; McNay and Gold 2002). In an experiment conducted with college students, ingestion of glucose led to increases of over 30% in participants' capacity to memorize text passages, in comparison with performance after ingestion of a control substance, the sweetener saccharin (Korol and Gold 1998). The result suggests that the positive cognitive effect of glucose intake is not simply due to its sweet flavor, of potential rewarding value, but in fact to the extra calories ingested. This aligns with recent evidence of separate circuits in mice for encoding the nutritional and hedonic values of sugar, with prioritization of energy-seeking over taste quality (Tellez et al. 2016).

Yet, the mere increase in caloric intake may be insufficient to produce cognitive gains. A study of the effects of fat-rich food in spatial learning in rats showed that animals fed with a low-fat diet took four sessions of daily training to achieve optimal task performance, while rats fed with a high-fat diet showed very slow learning: Even after 8 daily training sessions, their performance was nearly three times worse than that of the low-fat diet group (Valladolid-Acebes et al. 2011). Thus, as insistently pointed out by political figures such as Michelle Obama, the poor quality of school meals, with an excess of fat, may be partly responsible for the comparatively poor results for U.S. students in school performance tests, vis-à-vis students of other developed countries.

There are important interactions between food security and sleep. To investigate this relationship, 5637 men and 5264 women (all over 22 years old) were surveyed to obtain self-reported information about sleep duration, sleep latency, and sleep complaints. Women suffering from very low food security showed significantly shorter sleep duration than women with full food security. Men undergoing food insecurity reported significantly longer sleep latency than food-secure men (Ding, Keiley, Garza, Duffy, and Zizza 2015).

Researchers have yet to develop a school-based investigation of the acute effects on nutrition on academic performance. It is necessary to conduct empirical research in the classroom setting in order to quantify the cognitive impact of caloric intake, meal composition, and the role of micronutrients and hydration, as well as the effects of portion size, food frequency and the reward value of food. Furthermore, interactions with sleep and exercise must be assessed in detail.

Physical exercise

One of the most unhealthful consequences of living in excessively small houses is the lack of space at home for stretching or exercising, adding to the lack of infrastructure for sports in most low-income communities. Yet, exercise deprivation affects all SES strata: Decreased physical activity levels and increased body mass indices for the whole population have accompanied economic development, with dire human and economic costs (Ng and Popkin 2012). The human body is genetically programmed to move, requiring physical activity to maintain the best functionality of neurons and metabolism (Vaynman and Gomez-Pinilla 2006; Deslandes et al. 2009). There is ample evidence that physical exercise contributes to the prevention of cardiovascular and metabolic diseases (Fiuza-Luces, Garatachea, Berger, and Lucia 2013), but its impact on cognition has been greatly underestimated. Yet, in the past decade investigators have given increasing attention to the topic (Chaddock, Pontifex, Hillman, and Kramer 2011; Diamond and Lee 2011; Haapala et al. 2014; Masley et al. 2009).

Exercise can help improve specific cognitive functions not only in elderly, but also in children (Diamond 2013). Among the cognitive functions that are benefited by an active life style, the most important are the executive functions, comprising the inhibitory control, planning, working memory, decision making and cognitive flexibility (Diamond 2013).

Among the brain regions involved in executive functioning, the prefrontal cortex (PFC) is one of the most important and continues to develop until the third decade of life. This extended deployment makes the PFC especially susceptible to the influence of the environment, cognitive enhancement, and an active life style (Halperin and Healey 2011). Indeed, exercise contributes to increased activation of the frontal cortex and hippocampus, respectively involved in the formation of new memories and in motor control (Diamond 2001). The search for mechanisms of the cognitive benefits of exercise occurs mostly in animal models. In mice, research links voluntary exercise with an increase in the number of new neurons in the hippocampus (Van Praag, Kempermann, and Gage 1999). Since then, several studies have shown that, in addition to neurogenesis, exercise contributes to the angiogenesis, synaptic plasticity, and the increased synthesis of trophic factors and neurotransmitters (Duman 2005; Pereira et al. 2007; Van Praag 2009).

Mounting evidence points to a link between motor skills and overall academic achievement. In preschoolers, an evaluation of datasets from three longitudinal studies shows that fine motor skills are a strong predictor of later reading and math achievement (Grissmer, Grimm, Aiyer, Murrah, and Steele 2010). In a recent systematic review, Van der Fels et al. (2015) show a relationship between cognitive skills and complex motor skills (fine motor skills, bilateral body coordination, and timed performance). To assess how motor skills relate to academic achievement and cognition, we recently investigated 45 Brazilian children and adolescents (8–14 years old) (Fernandes et al. 2016), finding that motor coordination is a good predictor of school performance. We found significant correlations between motor coordination and several indices of cognitive function, which indicate that visual motor coordination and visual selective attention may affect academic achievement and cognitive function.

The relation between cardiorespiratory fitness and cognitive performance is also well established (Berchicci, Pontifex, Drollette, Pesce, Hillman, and Di Russo 2015; Pontifex et al. 2011; Voss et al. 2011). Exercises that develop aerobic capacity correlate with enhanced executive functions, greater activation of PFC, and improved school performance. Chaddock et al. (2010) showed that higher levels of aerobic fitness are associated with a greater capacity to inhibit a maladaptive response in a selective attention task.

In the learning process, attention seems to be a crucial challenge to educators. Classrooms are busy environments where students must sort relevant from irrelevant information. The slow maturation of the PFC imposes neuropsychological limits throughout childhood (Quartz and Sejnowski 1997), especially regarding short-term memory and attention. Physical activity might be key to improving attention in classrooms: the integration of exercise with the presentation of academic concepts in elementary school classrooms showed positive results in academic achievement (Donnelly et al. 2016) in accordance with the acute positive effect of exercise on attention (Hillman et al. 2008). Even a single session of aerobic exercise can facilitate cognitive performance in children. In tests of mathematics and reading, the best results were obtained after 30 min of moderate racing (Hillman et al. 2008). Physical education classes conducted immediately before lectures are likely to enhance academic performance due to acute responses to exercise, such as increased alertness, improved reaction time, and increased information-processing speed.

A meta-analysis by Fedewa and Ahn (2011) showed a positive effect of aerobic exercise on children's achievement and cognitive outcomes. Type, intensity, and volume of exercise were correlated with the responses, indicating dose–response effects. Lees and Hopkins (2013) showed positive impacts of interventions described as "aerobic exercise", in children's psychosocial function and cognition. However, these effects were minimal or not significant in several studies (Lees and Hopkins 2013). One possible explanation is the intensity and volume of exercise training. Investigators conducted a randomized controlled study with 67 Spanish adolescents to measure the cognitive and academic effects of increased time and intensity of physical exercise (Ardoy, Fernández-Rodríguez, Jiménez-Pavón, Castillo, Ruiz, and Ortega 2014). Three classes were randomly sorted into a control group with 2 weekly PE sessions, and two experimental groups with 4 weekly PE sessions, differing only in the intensity of the exercises. The high-intensity exercise group showed significantly higher performance in nonverbal and verbal ability, abstract reasoning, numerical and spatial abilities, as well as school grades, in comparison with the other two groups (Ardoy, Fernández-Rodríguez, Jiménez-Pavón, Castillo, Ruiz, and Ortega 2014).

Although most school-based research focuses on aerobic aspects, researched have begun to consider other variables. In children, acute bilateral coordination exercises (10 min) showed better effects on concentration and attention than normal PE lessons with the same duration (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, and Tidow 2008). There were no significant differences in the exercise intensity between the groups, which suggests that the coordinative characteristic of the exercises was responsible for the results (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, and Tidow 2008). Studies with racket-sports verified positive chronic effects of coordination exercises on visual perception and executive functions in children with developmental coordination disorder (Tsai 2009) and in children with mild intellectual disabilities and borderline intellectual functioning (Chen, Tsai, Wang, and Wuang 2015).

In this manner, using coordination exercises in schools might be an efficient tool to reduce learning delays in children with special needs. PE classes based on open-skill tasks, characterized by an unstable environment demanding continuous adaptation, showed better results in the executive functioning of overweight children, compared with standard PE classes (Crova et al. 2014). A school-based motor program, designed to stimulate executive function and attention performance in children, showed positive results in children aged 6–10 years (Cardeal, Pereira, Da Silva, and De França 2013). Open-skills activities tend to demand not only physical effort but also cognitive engagement. In this context, exercise programs capable of simultaneously enhancing aerobic capacity, motor coordination, cognitive challenges, and social integration, such as team sports and the Brazilian practice of Capoeira, are of special interest for school interventions.

Regardless of children's ages, economic-status, and cultural differences, the school must offer them physical exercise to facilitate learning and improve physical and mental health. All school components should provide, or encourage students to engage in, physical activity at least 60 min per day, 7 days per week (Kohl and Cook 2013). Schools face several barriers to implementation of quality PE programs, such as lack of facilities and time, crowded curricula, insufficient infrastructure, scarcity of PE teachers, and low levels of professional development (Kohl and Cook 2013). Educators must design lessons to integrate physical activity with other subjects, in order to facilitate learning and improve academic performance.

Assessment of individual learning

One important bottleneck for education in crowded environments is how to assess learning individually in order to properly adapt teaching strategies. Given how crowded typical classrooms are across the world, it is extremely difficult to orient activities and learning strategies that better fit students individually; the identification of each student's deficits and potentials surpasses even the most well trained teacher. This need goes beyond measuring academic achievement—it points to behavioral and cognitive assessments that can predict learning deficits early enough for teachers and families to intervene.

Most cognitive and behavioral tests use norms based on populations with specific cultural features—namely, those who live in Western, educated, industrialized, rich, and democratic countries—which are not representative of cognitive development in low-SES societies (Henrich, Heine, and Norenzayan 2010). To build specific norms for each population seems a challenge for countries with low investments in research and education. Fortunately, new technologies and analytical strategies related to the advent of "big data" bring hope to the field (Goldin et al. 2014; Lomas et al. 2013; Lopez-Rosenfeld et al. 2013; Méndez et al. 2015; Mota, Copelli, and Ribeiro 2016; Odic et al. 2016). For instance, Adaptive Collaborative Learning Support (ACLS) (Magnisalis, Demetriadis, and Karakostas 2011; Walker, Rummel, and Koedinger 2014) is one way to deal with this complexity. Developers have come up with educational softwares, modelling collaborative learning, to create rich learning environments that adapt to each student's characteristics, helping to improve achievement beyond the mere assessment of performance. The system provides intelligent feedback that guides the student in finding his or her best individual learning pathway.

Regarding such computational approaches, we have developed speech analyses that are successful on cognitive deficits associated with pathological conditions such as dementia (Bertola et al. 2014) and psychosis (Mota et al. 2012, 2014), and can even predict psychotic breaks more than 2 years in advance during the prodromal phase, i.e. during the initial stages of the disease when symptoms are not very apparent (Bedi, Carrillo, Cecchi, Slezak, Sigman, Mota, Ribeiro, Javitt, Copelli, and Corcoran 2015). These approaches use structural and semantic features measured on free speech recorded naturalistically, and were successful in low-SES environments in Latin American countries (Mota et al. 2012, 2014; Mota, Copelli, and Ribeiro 2016). Cognitive deficits related to temporal abilities impaired by attention-deficit/hyperactive disorder (ADHD) could be correctly measured by gamelike software, and the discrimination function classified 82.4% of the cases (Méndez et al. 2015). Given the success of computational behavioral analysis in characterizing cognitive deficits, we have great hope that they can also be used to characterize cognitive gains in the school environment. We have recently set out to measure speech structure from memory reports of 76 children (6–8 years old), recorded in the school environment in low-SES communities. We found that several structural features of speech are correlated with intelligence quotient (IQ) and theory of mind (i.e. knowledge that other people also have a mind), as well as school performance on math and reading (Mota, Copelli, and Ribeiro 2016; Mota et al. 2016).

Designed softwares and educational games based on developmental sciences are useful, low-cost tools to assess learning; they enable specific interventions based on recognized deficits assessed by individual learning curves compared to the learning curve of peers. This strategy is poised to enable physiological inputs like sleep, nutrition, or exercise to positively reinforce significant cognitive shifts within minutes to hours of their detection. Big-data analysis is a powerful new reality that has been revealing surprising results regarding motivation and learning, for instance (Lomas et al. 2013). With the students' frequent use of automated tools, it is possible to build a big dataset specific to their environment, which analysts could then use as a model to search for learning patterns. In principle, this approach would help avoid the mistake of interpreting cultural differences as deviances from the norm.

Investigators have shown that using technology is effective in assessing, and intervening in, the learning processes in schools in low-SES countries (Goldin et al. 2014; Lopez-Rosenfeld et al. 2013; Odic et al. 2016), as verified by the experiences of the Argentinian Joaquín V. González program (http://www.programajoaquin.org/) and the Uruguayan CEIBAL program (http://www.ceibal.edu.uy/), both part of the worldwide initiative One Laptop Per Child (OLPC) (http://www.laptop.org/), which delivers and manages one low-cost laptop per student.

Samples of more than 500 children in Uruguay (Odic et al. 2016) revealed notable discoveries regarding math learning and abilities to estimate time and quantity. In Argentina, an intervention applied through games in schools of low-SES communities showed cognitive benefits for 6-to-7-year-old children, with transfer to some executive functions and some equalization of academic outcomes between children who regularly attend school and children who could not attend for different reasons (Goldin et al. 2014).

It is now possible to envision a future in which fun and motivating computational tools will allow teachers and researchers to assess each student very frequently (for instance, practicing 10 min/day on a computer game involving math or reading skills) so as to quickly build an individual dataset. Using machine learning approaches, it is possible to build a student's learning curve and compare a variety of features (accuracy of answers, reaction times, language elements) with those found in peers in the same classroom, school, city, or country—comparing within and across SES cohorts. In a few weeks one could have enough data from each individual to identify learning patterns to reward as well as deficits to remedy. This would allow teachers to quickly adapt their teaching strategies, and even to suggest new motivating approaches based on the student's potential as assessed in other disciplines.

Toward healthy, cyclical inputs to strengthen learning

Health and education gradients are related to the fact that low-SES subjects are exposed to a systematically higher risk for worse health outcomes, morbidity, and mortality (Mackenbach and Howden-Chapman 2003; Mackenbach et al. 1997). Inadequate sleep, nutrition, and exercise have a compound negative impact on youth cognition, academic achievement, and quality of life. To have schools compensate for the physiological deficits suffered by low-SES youth is key for education improvement. Low-SES children and adolescents are at the most severe risk for poor outcomes; amelioration of the physiological conditions that prepare and consolidate learning is likely to maximize gains for these students.

Cognitive improvement from mitigation of physiological deficits depends on the time between physiological intervention and acquisition of new knowledge, on the scale of minutes to hours. To achieve that, automated assessment of individual student performance is of the essence. Systematic, dense mapping of cognitive trajectories will give educators a much better grasp of the appropriate psychological and physiological interventions, allowing for personalized and yet scalable education. In developing countries with blatant educational inequality, overcoming physiological and assessment bottlenecks is likely to generate major cognitive benefits in the poorest strata of society. From the point of view of public policies, these bottlenecks are "low-hanging fruit"—goals relatively easy to achieve. Schools can become places where attending classes, eating, sleeping, exercising, and undergoing examinations alternate in a cyclical manner so as to optimize learning. Regular classes—often long and boring—could be replaced by shorter, more effective classes so as to free time for physiology and assessment activities. Educators will focus much future research on how to best schedule and design these activities.

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