



Global Sustainable Development priorities 500 y after Luther: *Sola schola et sanitate*

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Martin Luther succinctly summarized his theology in *sola* statements, such as *sola scriptura*, viewing the Bible (*scriptura*) as the only valid source of information about God rather than what he viewed as the extraneous, corrupting church doctrine of the time. As a secular side effect of this focus on individual reading skills, the Protestant territories were the first to acquire high literacy rates, which subsequently fostered health, economic growth, and good governance. Here I argue that a similar priority focus on empowerment of all segments of all populations through education and health (*sola schola et sanitate*) is needed today for sustainable development. According to decades of research, education and health are essential prerequisites for ending poverty and hunger, for improving institutions and participation in society, for voluntary fertility declines and ending world population growth, for changing behavior and adoption of new and clean technologies, and for enhancing adaptive capacity to already unavoidable climate change. This approach avoids paternalistic imposition of development policies by focusing external aid on enabling people to help themselves, their families, and communities. Prioritizing education and health also helps move more industrialized, aging societies from a focus on material consumption to one on quality of life. *Sola schola et sanitate* suggests that well-being will increasingly be based on health, continued mental stimulation, and consumption of cultural products, rather than fossil fuels and materials. Thus, cognition—or brain power—can be viewed as the zero-emissions energy for sustainable development.

Sustainable Development Goals | reformation | education | health | world population

On October 31, 1517, Martin Luther released his famous 95 Theses, which openly challenged church authorities on the practice of selling indulgences. This happened in a period of transition in Europe with Humanism and Renaissance culture spreading, new discoveries being made in geography and science, and the printing machine revolutionizing communication. But this specific date is widely considered as the start of the Protestant Reformation, which triggered a series of highly consequential religious, political, and socioeconomic developments, not only for Germany but also for the world. In particular, the Reformatory emphasis on universal literacy, allowing all women and men alike to read the Bible themselves, led to far-reaching changes. As I will discuss below, this spread of education has ever since been a key factor in the advance of health and technology, subsequent economic growth, and lasting improvements in human living conditions.

On September 25, 2015, the political leaders of the world assembled at the United Nations in New York and defined a set of 17 Sustainable Development Goals (SDGs), including 169 specific targets that were approved by 193 countries. This followed an extensive international consultation process, with hundreds of discussion fora around the world, including governments and civil society. The resulting set of goals updated the earlier eight Millennium Development Goals (MDGs) and significantly expanded their scope. Importantly, the SDGs do not only apply to developing countries but are formulated as (nonbinding) commitments for all

193 countries. Will these global goals that have been endorsed by the broadest possible coalition of governments and civil society around the world trigger a globally transformative power comparable to the teachings of a single monk 500 y ago?

Although the answer to this question will only be known in retrospect, it is possible to make some informed observations about the preconditions for success. Here I will propose and discuss the thesis that a successful global transition to sustainability will require as a necessary prerequisite the emphasis on core priorities, similar to Luther's famous *sola* principles, rather than the technocratic implementation of 169 diverse targets. In Medieval Latin, *sola fide* emphasized that salvation can only come through direct faith in God, without the mediation of saints or having to worry about the countless behavioral norms defined by the church. It has been called the all-decisive core of the Reformation (1), with everything else—including moral behavior and the organization of many aspects of life—following from this first principle. Such a focus on decisive first principles from which everything else follows was key to the transformative power of the Reformation and, I would argue, could again be the key today for the transition necessary for securing sustainable well-being. Education and health for all—*sola schola et sanitate*—can be viewed as such first principles, which present ends in themselves (i.e., they have intrinsic value) and are essential means and key catalysts for pursuing the rest of the sustainable development agenda (i.e., they have instrumental value). They are essential prerequisites for enabling people to eradicate poverty, to organize their societies in equitable ways, to control those in power, and to manage the planet in a way that allows all humans to prosper for many generations to come.

Significance

In 2015, all countries of the world agreed to an ambitious set of 17 Sustainable Development Goals, including 169 specific targets. Whether these goals will be achieved and lead to the desired sustainability transition will depend on the degree to which they can energize and mobilize policy makers, donors, nongovernmental organizations, private industry, and the public. There is a fear that this rather technocratic set of 169 overlapping and partly contradictory targets lacks the sense of clear priority that is needed. This paper proposes a clear priority focus on human capital (education and health) as a root cause of development that, together with maintaining natural capital, is prerequisite for all other Sustainable Development Goals, offering a vision for an achievable and sustainable future.

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This first principle puts people first, who—enabled through health and education—will become empowered to not only help themselves and others, but also to manage our societies, our economies, and our planet sustainably. In the context of sustainability science (2) and the distinction between the relative contributions of human capital, natural capital, and produced capital to sustainability or the Inclusive Wealth Index, this is fully in line with the empirical findings that under current conditions, changes in education and health have by far the highest impact (3, 4). In other words, just as the instrumental value of reading was recognized by the Protestant movement as a way to enable salvation, I would argue that the international community should recognize the instrumental value of education and health as a way to enable sustainable development.

In this paper, I will elaborate the science behind this people-centered view of sustainable development by building on an extension of my own scientific discipline, demography, which I like to define as the mathematics of groups of people. Demography not only has human beings and their characteristics at the very center of its analytical models, but it also has the longest prediction horizon of all social sciences because of the fact that the average lifespan of humans today is 70–80 y and many relevant characteristics of people are formed at a young age and thereafter remain fixed. The resulting model of demographic metabolism can quantitatively show how societies gradually change through the replacement of generations (5). This will be illustrated here in terms of the dynamics of human capital formation: that is, the changing number of people by health status and education/skills.

A concentration of development efforts on basic health and education for all also has an important policy dimension in enhancing equity within countries and between countries. Not so many decades ago the world was split into colonial powers and their colonies and some scholars claim that this power gradient still exists today, largely between richer and poorer countries. Hence, implementing predefined development goals through international organizations, such as the United Nations and the World Bank, as well as aid agencies of the rich countries, suggests to some observers a technocratic top-down approach that has been labeled “The Tyranny of Experts” (6). Some authors go as far as to claim that on balance international aid has done more harm than good to local communities, including the strengthening of corrupt elites (7). But even if some of these allegations are justified, the suggestion to stop all aid throws the baby out with the bathwater. Acquisition of basic health and education enables populations in developing countries to define their own priorities and organize their societies accordingly: it helps people to help themselves.

In this Inaugural article I will take a very long-term and broad perspective on development. I will not only reach back 500 y, but also look forward many decades, through discussing alternative possible narratives and associated numerical scenarios for the 21st century. This paper emphasizes the fundamental role education and health play in sustainable development by presenting scientific evidence regarding how human capital leads to different dimensions of development, including economic growth, good institutions, demographic transition, and enhancement of adaptive capacity. I will also address the causal mechanisms described in the neurological literature, through which schooling enhances cognitive functioning through increasing the synaptic density in relevant parts of the brain, thus influencing our perceptions, time horizons, and our behavior. Because global health has recently received much more international attention and funding than education, here I will give more attention to the latter, although both have to be viewed as a closely related couple of empowerment and quality of life. I will conclude by pointing out that *sola schola et sanitate* is also a valid priority for the most industrialized countries, moving the emphasis away from material consumption to a focus on quality of life. All this will show how brain power is the potentially unlimited zero-emissions energy for a sustainable future.

Reformatory Emphasis on Literacy for All

For most of the 5,000 y since writing was introduced in Mesopotamia and Egypt to keep simple accounts about stocks of grain delivered and other administrative purposes, literacy skills tended to be restricted to a tiny elite. Literacy was primarily limited to religious leaders, state servants, far-traveling traders, members of specialized guilds, and certain nobility (8). There are two known exceptions to this: in ancient Athens in the 5th century BCE and in 15th century towns in Tuscany. In both cases, there were interesting interactions with democracy in the way in which being able to write (e.g., the name of a person who should be ostracized by the assembly of the demos of Athens) was a prerequisite for exerting democratic rights, and conversely, the rights were an incentive to acquire basic literacy (9). It should be noted, however, that in both cases the skills and rights were limited to the male population that held rights of citizenship, a minority of the total population.

At least since the time of Confucius 2,500 y ago, some scholars have expressed the hope that all people should get the opportunity for education, but Martin Luther seems to have been the first to consistently and successfully campaign for all ordinary people—women as well as men—to be taught to read (and write). Luther's motivation for this was primarily religious because he was convinced that human salvation was only possible through a personal relationship with God, which in turn could only be achieved if believers were able to read the Bible for themselves. This was why Luther translated the Bible into a German vernacular that everybody could understand. However, because few people at the time were able to read or write, Luther made the establishment of schools for everybody in Germany a priority. In the spring of 1524 Luther wrote his pamphlet, “To the Councilmen of all cities in the German lands, that they should establish and maintain Christian schools” (10). In this work, Luther called for children to be taught more than was necessary for earning their daily bread. This is a very important foundation for the later spread of literacy in the Protestant territories, where it preceded economic growth, thus challenging the frequent assumption made by economists that the spread of education was a consequence of responding to economic incentives. It can be shown that almost universally the spread of literacy for noneconomic reasons preceded economic growth (11). It was for religious and not economic reasons that Luther and his closest associate, Melancton, wanted every boy and girl—including “*das geringste Mägdelein*” (“the lowest level maid”)—to be able to read the Bible.

It is worth noting that this ambition was not shared by the leading intellectuals of his time. Erasmus of Rotterdam (1466–1536), the most influential Humanist of the early modern era, was in fact highly critical of Luther's vulgarization of education, which was highly suspect to the elitist Humanists used to communicating in Latin and Greek. To spread the word, Luther made extensive use of the new media of his time, printing his tracts and pamphlets in the form of leaflets, posters, and broadsheets. Thanks to the printing press, invented and operationalized by Johannes Gutenberg (1400–1486), and the post coach system, these could be sent from Wittenberg to anywhere in the German Empire within a matter of days (11). No wonder Luther praised book printing as “God's highest and greatest gift of grace” (12). The introduction of compulsory schooling for all girls and boys clearly followed the Reformation and was introduced in Protestant areas from 1592 onward.

As a consequence of this emphasis on universal literacy, the Protestant territories in Northern Europe gradually became the most literate populations of the world, although there were some interruptions, such as the Thirty Years' War. In fact, one could argue that the rise of The Netherlands and England as colonial powers, and the parallel decline of the much less-educated Catholic powers of Spain and Portugal, were in part because of this factor (11). Statistics from The Netherlands show that already around

1600, two-thirds of men in the cities could read and write. Around 1850, about 80% of the population—including those in rural regions—were literate. The same thing happened in England, where around 1800 60% of all men and 40% of all women could read and write (13). Looking at a map of Europe around 1870, the clear association between literacy and religion is evident (13). The Protestant territories of Sweden, Germany, The Netherlands, and Great Britain are undisputed leaders with literacy rates of around 80% at this time. They are followed by France, which after the French Revolution (during which the Catholic Church became less central) managed to raise its literacy rate to 69%. Austria and Ireland (both Catholic) rank after France. Italy and Spain (both Catholic) lag a long way behind, with rates below 35%. Russia reaches 15% literacy and Turkey 9%.

This ranking by level of literacy in 1870 matches almost exactly the degree of economic development at that time. Interestingly, recent research suggests that this association of religion and development is not so much attributable to Max Weber's famously hypothesized effect of "Protestant Ethics," but that the economic head start of Protestant regions can be more easily and more directly explained by their better-educated populations (14). In fact, the French sociologist, Emmanuel Todd (15), describes the progress of humankind as a direct function of the spread of literacy in populations. Comparing the evolution of literacy rates around the world, Todd suggests that a critical threshold for socioeconomic change and even political revolutions is reached around the point when 50% of male adults are literate. He sees the progress of human history as driven by the progress of the human mind, with the slow rise of literacy being even more influential in the long run than the Industrial Revolution.

The hypothesis that literacy of broad segments of the population is a necessary prerequisite and root cause of subsequent economic development (16) is also consistent with evidence outside of Europe. Goldin and Katz (17) describe how the United States became the world's best-educated population by the early 20th century, mostly through public education, and that this was the decisive prerequisite for becoming the leading economic and political power by midcentury. This description is fully consistent with the rise of Japan, which in the late 19th century under the Meiji Dynasty started to copy the Protestant European school system and, already in 1900, had a primary school enrollment rate of 90%. The resulting educated young adult population was the basis for Japan becoming the leading economic and military power in Asia during the first half of the 20th century. The experience of the "Asian Tigers," such as South Korea and Singapore, further illustrates this pattern, where massive expansion in human capital after World War II preceded rapid economic growth. An early emphasis on universal female basic education was also the key policy for the island of Mauritius, which in the 1960s served as a textbook example of a country trapped in the vicious circle of poverty, high population growth, and environmental destruction, to become one of the most highly developed countries in the African region today (18).

How Human Capital Fosters Economic Growth and Better Institutions

Human capital is a fundamental prerequisite for economic progress and good institutions, key components of sustainable development. At the level of individuals, empirical evidence shows beyond any reasonable doubt that more years of schooling, on average, lead to higher income. This pattern can be found in virtually all countries, and discussions only concern the specific patterns or changes over time in this so-called education premium. However, at the macroeconomic level, empirical evidence relating changes in education measures to economic growth has been rather ambiguous until recently. Many authors suggested that this may be because of problems with the global empirical data on human capital (19–21). Indeed, the usual human capital indicator

in the form of mean years of schooling of the entire adult population does not adequately reflect recent improvements of the education of younger cohorts. As Fig. 1 illustrates, under conditions of very rapid education expansion the young adult cohorts, who are decisive for economic growth, can already be highly educated, whereas the mean years of education indicator can still be depressed through the still uneducated older cohorts. In analyses that explicitly consider the age structure of human capital growth, regressions unambiguously confirm the key role of human capital in economic growth (22). In addition, using the full range of the educational attainment distribution by age in economic growth regressions (i.e., the colored population pyramids as shown in Fig. 1) results in findings of great policy relevance: for poor countries with very low levels of education, only the combination of universal primary education with broadly based secondary education results in the kind of rapid economic growth that has the potential to push countries out of poverty (22). This important insight is also reflected in the SDGs: whereas the earlier MDGs only called for universal primary education, SDG4 calls for universal high-quality primary and secondary education.

Another series of recent studies highlights the importance of improving education for the quality of institutions. Some development economists see institutions as the key factor for development (23), but good institutions do not fall from heaven nor can they be imposed from outside; rather, they are gradually built up by informed and empowered people. The same is true for the spread of liberal democracies. Following Lipset (24), an increasing level of education helps individuals to develop a stronger sense of civic duty and greater interest in politics, thus leading to more political participation. Several empirical studies indeed find a positive association between education and democracy even after controlling the possible effects of economic growth (25, 26). Comprehensive econometric studies based on age-specific educational attainment distributions of men and women in 120 countries since 1970, and also controlling for gross domestic product per capita, the investment rate, life expectancy, the urbanization rate, the share of agricultural output on total output, and the change in the young-age dependency ratio, show several interesting findings: societies with high proportions of young people tend to have a lower probability of achieving democratic regimes; increases in urbanization and investment tend to lead to political changes in the direction of democratization; and education turns out to be a significant and robust determinant of democracy. With respect to gender differentials, the findings also show that an increase in female relative to male education is a robust predictor of changes toward more democratic rights (27). Many of the empirical findings concerning the benefits of expanding education depend on a proper consideration of changing human capital by age-cohort and gender. This is where demographic models can make an important contribution.

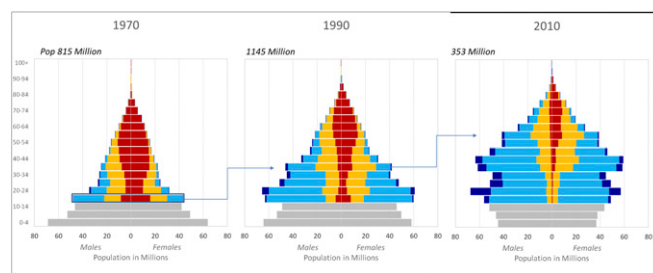


Fig. 1. Reconstructed age and education pyramids for China 1970–1990–2010. Note: Population under 15-y-old represented by gray color not disaggregated by educational attainment.

The Demographic Metabolism Model of Social Change Through Cohort Replacement

Multidimensional demographic methods can model how societies change as a consequence of changes in population composition by important human characteristics. For example, in any given society, the individual characteristic literacy does not change for all members of the population at once. Literacy is typically acquired in youth and then maintained throughout the life course. At the population level, this implies a gradual process during which first the proportion of literate young people increases, who then move up the age pyramid in a predictable way, whereby they step-by-step increase the proportion of those who are literate among the adult population. The multidimensional model capturing such dynamics has been labeled “demographic metabolism” (5), a model which is demographic in its approach and origin but can be applied far beyond what are conventionally considered to be demographic questions. This model is a tool for quantitative social forecasting at a time scale of several decades, a horizon needed for discussions of sustainable development priorities.

Demography is the scientific discipline that studies the changing size and composition of populations. Historically, demography developed out of what used to be called “political arithmetic.” It has a long tradition of forecasting future population trends for various government functions, ranging from military to health to social security systems. For modeling population dynamics, traditionally, populations were assumed to be fully homogeneous and projections were simply done by applying an assumed growth rate to a given initial population size. Because the base population is growing over time, this implies a model of exponential population growth. Although birth and death rates vary strongly with age, in case of rather stable age structures this provides a useful approximation and it is still widely used (e.g., in animal demography). However, for human populations after the beginning of fertility declines and the strong fluctuations in births and deaths associated with World War I, the Spanish Flu, and the Great Depression, age structures in Europe had become very irregular. As a consequence, most population projections since the middle of the 20th century have been based on an age-specific model, called the “cohort-component model,” which projects populations along cohort lines (e.g., the cohort aged 20–24 y in 2015 becomes 25–29 y in 2020) based on assumptions for the three components of population change: fertility, mortality, and migration. Currently, population projection models that differentiate populations by age and gender still dominate the field. However, multidimensional population models can subdivide populations by many other relevant and observable individual characteristics: that is, sources of heterogeneity that influence population dynamics. These models also forecast along cohort lines: for example, the proportion of women with high school graduation aged 25–29 y in 2015 is a good predictor of 60- to 64-y-old women with high school graduation in 2050, after accounting for mortality and migration. Because in most populations both fertility and mortality tend to vary greatly with level of education, explicitly accounting for educational differences also changes the population forecasts themselves (28).

This model of population change along cohort lines has recently been generalized to a model of social change with predictive power, called demographic metabolism (5). Building on earlier work of the sociologist Karl Mannheim (29) and the demographer Norman Ryder (30), this concept operationalizes the age-old view that societies change as a function of young generations, which are different in relevant ways, successively replacing older ones. For Ryder, intercohort change was the only source of progress and, in his view, “a population whose members were immortal would resemble a stagnant pond” (31). In recent generalizations this model also allows people to move from one subpopulation to another (e.g., from secondary to tertiary education), thus combining transitions over the life course, with the effect of intercohort replacement (5).

These movements between different subcategories of each cohort can be described through a set of age- and gender-specific transition probabilities (32). Hence, the model of demographic metabolism can analytically describe and, under certain assumptions, forecast how societies change as a consequence of compositional changes in relevant and measurable characteristics of their members.

This compositional change through successive generational replacement can be illustrated in the form of 3D age pyramids. For the case of China, Fig. 1 shows in different colors the proportions of men and women in different age groups who have different levels of education. In the figure, one specific cohort is highlighted through blue lines across the different pyramids to better illustrate this upward movement of identical cohorts with the passage of time. In 1970, China was still an extremely poor developing country with a fertility rate of more than six children per woman and, as a consequence, a very young age structure, with more than half of the population below 20 y of age. The red color on the right (female) side of the pyramid also shows that the vast majority of Chinese women had no formal education at all. Only for the young age cohorts does the expansion of basic education that had started in the 1940s show an increase in the proportion with some primary or junior secondary education. As in virtually all countries, the education expansion started first for men and only later extended to women, and this is why in every age cohort men have somewhat higher education than women.

For the pyramid in 1990 in Fig. 1, we see that the entire education pattern has essentially moved up the age pyramid by 20 y. In 1990, the better-educated younger cohorts had reached the main working age, which was also an important factor driving the rapid economic growth that started after the economic policy reform of 1979. By 2010, the education structure had moved up another 20 y and, as a consequence of improved female education together with the Chinese family planning policy, the birth rates strongly declined. Over the last half century, the demographic metabolism process has fundamentally transformed Chinese society.

The demographic metabolism model does not only hold for the changing educational composition but can be applied to other relevant characteristics that tend to be persistent along cohort lines. For example, younger generations who get environmental education and hold more postmaterialistic values than the older ones (33) can be expected to gradually change the overall environmental attitudes of societies as they move up the age pyramid. The model has already been applied numerically to forecasting the changing prevalence of attitudes toward gender roles (34, 35), homosexuality (36), and European identity (37), where younger and older birth cohorts differ mainly because younger generations were socialized in different social environments. Based on this model, it has recently been shown that the fact that young people across Europe express to a greater extent a European identity on top of their national ones has been the reason for the expanding prevalence of European identity and will likely continue in the future, irrespective of current political turmoil in the European Union (38). In general, this model works well for deeply rooted attitudes and identities that are formed at young age, and are largely maintained throughout the rest of life. Its predictive power is much weaker for volatile specific opinions and behaviors.

The Causal Mechanism: What Education Does to Our Brains and Our Behavior

Outside of education research, social scientists often view education as just one dimension of social stratification that is a consequence of the class structure of society. Economists tend to see it primarily as an investment made to get higher wages on the labor market. Although educationists have long conceptualized education as an independent force that changes the way we perceive the world and behave, outside of the field this view has rarely taken hold. However, there is no doubt that education effects our cognitive functioning, affects our behaviors, and at the same time

equips us with better social and economic opportunities. Most directly, the mental stimulation experienced when learning—be it in school or through informal channels—enhances cognitive development through increasing the synaptic density in relevant parts of the brain (39). Many experimental and observational studies have provided confirmation of a robust effect of education on executive functioning and cognitive abilities (40–42); neurocognitive and neuroimaging studies have also shown strong associations between adaptive changes in the brain and learning experience in classrooms (43). Abstract cognitive skills, such as categorization and logical deduction acquired through schooling, enhance the way educated individuals reason, solve problems, assess risks, and make decisions (44). This has been most extensively documented with respect to the well-established causal link from education to health (45, 46).

Education, Health, and Income

When studying the complex interactions between education, health, and income and the associated questions concerning the direction of causality and possible endogeneity, it is essential to distinguish between education flows (schooling) and education stocks (human capital). Attending school and successfully graduating can depend, among many other factors, on the health status of the child as well as on household income and national economic growth. However, once a person reaches his or her highest educational attainment, this by definition stays invariant over the rest of the life cycle and cannot any more be influenced by other factors. At the same time, human capital (educational attainment) can influence health-related behavior as well as economic productivity for the rest of the life cycle. Hence, there is a causal effect from human capital (stock) to health and income, but no simultaneous effect in the opposite direction. Income and health can only influence schooling (flow), which only changes average human capital with a delay of several decades.

Clearly, a certain minimum level of physical health is necessary for a child to develop mentally and to be able to attend school. Particularly in developing countries, school absenteeism as a result of poor health of the children themselves or of family members they have to care for, is a serious handicap for improving levels of education and, consequently, the building of key cognitive skills and raising learning outcomes. Environmental factors, such as air pollution, can also have serious implications on cognitive development, thus constituting an effect of the depletion of natural capital on human capital formation (47). The cognitive skills resulting from education and the health status of a person are both embodied in individuals, in contrast to income, which is not embodied.

In virtually all countries of the world, more educated mothers experience lower child mortality. However, because often more educated people also live in richer households, the question arises: What is more important for child survival in developing countries, mothers' education or household income/wealth? This has been the explicit focus of a series of studies using the widest existing individual-level dataset by pooling the samples of Demographic and Health Surveys in 43 developing countries (48, 49). Using multilevel regression models, the analysis of the relative effects of mother's education and economic resources on infant mortality shows that both within families and within communities, the effect of education clearly dominates over income/wealth.

The empirical evidence is equally compelling for the effect of education on adult mortality. In virtually all countries for which data exist, more educated people have higher life expectancies (50). The differences vary in extent among countries and are generally greater for men than for women. Among industrialized countries, mortality differentials tend to be lowest in Southern European countries—presumably because of the healthy Mediterranean diet of all social strata—and are highest in Eastern Europe. In Russia, the difference in life expectancy between the highest and lowest education groups among adult men is up to 12 y (50). It has even

been shown that the overall decline in life expectancy that Russian men experienced over the 1990s was driven by a strong decline among the lower education groups, whereas the highest groups continued to enjoy moderate increases (51). In virtually all industrialized countries for which data are available, the education differentials in adult mortality increased over time despite improving health care coverage in most countries (50). For the United States it was shown that the recent rise in morbidity and mortality in midlife among white non-Hispanics has been concentrated among the low-education groups (52). For China, a new study finds large and increasing educational gradients in a context of broadly declining mortality (53).

One possible explanation for this pattern lies in the increasing importance of lifestyle-related factors for which education seems to be more important than the healthcare system. This positive effect of education on longevity even seems to hold for the very top of the education distribution, as shown for members of national academies of sciences. Because good records exist for most learned societies about the age of death of their members, these historical time series have been compared with that of the general population (54). Fig. 2 plots the remaining life expectancy at age 60 y for members of the Austrian Academy of Sciences (previously Imperial Academy of Vienna) since 1870 and compares it to that of the general male population of Austria (in earlier times all Academy members were men). Interestingly, up to World War II, academicians had almost no survival advantage, even though they included some of the world's foremost physicians at the time. Over recent decades, however, a clear advantage for academicians emerged, who now have a remaining life expectancy at age 60 y that is even 3–4 y longer than the general male population with at least a Master's degree. It has been suggested that this survival advantage is not a result of selectivity or better access to medical care, but rather because of continued demanding mental activities to very high ages (55).

Better health and longer lives are not only closely linked to education and cognitive capacity but also in turn directly affect economic growth. A burgeoning body of literature shows that health is not only a direct source of human welfare but also a driver of income growth. In particular, three mechanisms have been defined: (i) better health, leading to higher labor productivity; (ii) better childhood health, leading to better school attendance and cognitive development; and (iii) a longer expected life span, leading to more savings and investment. Empirical studies also find that good health has a positive, sizable, and statistically significant effect on aggregate

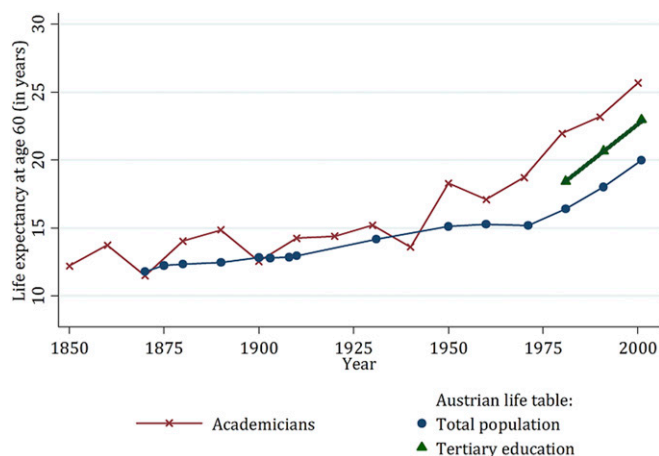


Fig. 2. Trend in life expectancy at age 60 y in Austria since 1850 for the general population, as well as members of the Austrian Academy of Sciences and the entire population with an academic degree (only male populations). Data from Winkler-Dworak (54).

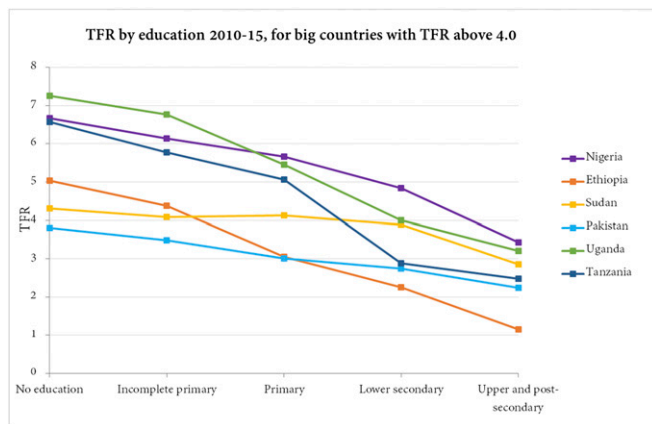


Fig. 3. Total fertility rate (TFR) by education 2010–2015, for big countries with TFR above 4.0. Data from Lutz et al. (62).

output, even when the experience of the work force is being controlled for (56). The WHO-sponsored report of the Commission on Macroeconomics and Health (57) also highlighted the importance of basic health for poverty reduction by showing how the burden of diseases in some low-income countries, especially in sub-Saharan Africa, stands as a stark barrier to economic growth, and therefore should be addressed centrally in any comprehensive development strategy.

Is there a feedback from economic growth to higher school enrolment? Based on the timing of changes, the global historical evidence in industrialized countries and in developing countries today suggests that improved basic education was generally more a function of political will rather than rising incomes. With a strong political will cost becomes secondary because primary school teachers in poor countries do not earn much and village schools can be rather primitive. The expansion of higher education, on the other hand, does require a certain degree of economic development to pay for it, and also to offer appropriate jobs for the graduates in which they can use their skills productively. This interaction between income and education can work as a self-reinforcing beneficial circle of development—as demonstrated by the Asian Tigers and by Mauritius in the African context (16, 18)—but it does require a strong initial focus on universal basic education. Investing in elitist education amid illiteracy has not worked well in South Asia and many parts of Africa.

Girls' Education and Fertility Decline

It has been long established in demography that education is one of the most important, if not the single most important covariate of both fertility and mortality/health. Consistent patterns of fertility differentials by mothers' education have been found from medieval times to the present in virtually all countries and at very different stages of economic developments (58). The differentials are particularly pronounced in countries during the process of demographic transition, when death rates have already fallen and birth rates start to fall after a certain time lag (59). Only in recent years in the Nordic countries does the gradient seem to flatten or show a mild U-shape because more educated women can arrange their lives better in a way to actually achieve the two-child norm, which is still almost universal in Europe (60). More generally, the empowering effect of education brings women in high-fertility settings to want fewer children and find effective ways to have fewer children. They generally want fewer children for health reasons, as many births at short intervals can be a major risk in the absence of effective health services, and because of value change, preferring fewer children who each will have better life chances, and possibly because of higher opportunity costs. Furthermore,

better-educated women can better resist the traditional pronatalist norms in their societies and resist the often higher fertility desires of their husbands (61).

The empirical evidence for a strong fertility-reducing effect of education in today's high- and medium-fertility countries is overwhelming, although there are some country-specific peculiarities. Fig. 3 shows comparable data based on recent surveys (62) for fertility levels (period indicator of children per woman) by mothers' education for six big countries with more than four children on average. The two biggest countries, Nigeria and Ethiopia, show almost linear slopes, with a similar gradient but at different absolute levels. Nigeria shows around 6.6 children for women without any formal education and 2.9 for those with postsecondary education. In Ethiopia, these fertility rates are 5.0 and 1.1 respectively. In Sudan and Pakistan the education gradients are a bit weaker but still clearly pronounced. Similar strong education gradients can be found with respect to desired family size and contraceptive use (61). Studies on the causes of educational fertility differentials in Africa consistently show that better-educated women want fewer children, have greater autonomy in reproductive decision-making, more knowledge about and access to contraception, and are more motivated to use contraception (63).

These pervasive education differentials have also been incorporated into models of population dynamics that stratify populations not only by age and sex but also by levels of education (28). Because female education is associated with lower fertility at the individual level, populations with higher proportions of better-educated women have lower overall fertility rates. This fertility factor by far outweighs the higher child survival rates associated with better education of mothers, which works in the direction of higher population growth. Combining both forces, better female education will lead to a sizable long-term reduction in the population growth rates. A quantification of the pure education effect has shown that assuming identical sets of education-specific fertility trajectories for all countries, a scenario assuming constant school enrollment results in a world population size by 2050 that is 1 billion higher than under a scenario of rapid school expansion (28).

More recently, an effort to translate all relevant health and education-specific targets specified in the SDGs into alternative trajectories of world population growth by using the above-described multidimensional demographic model resulted in a peaking of world population around 2060 and a total size of between 8.2 and 8.7 billion in 2100, depending on different interpretations of the education SGD (64). Because of the lower

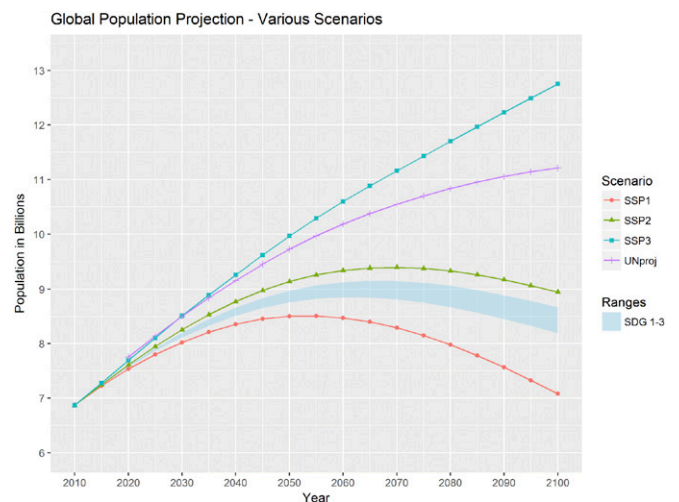


Fig. 4. Various population projections, various scenarios. Data from Abel et al. (64).

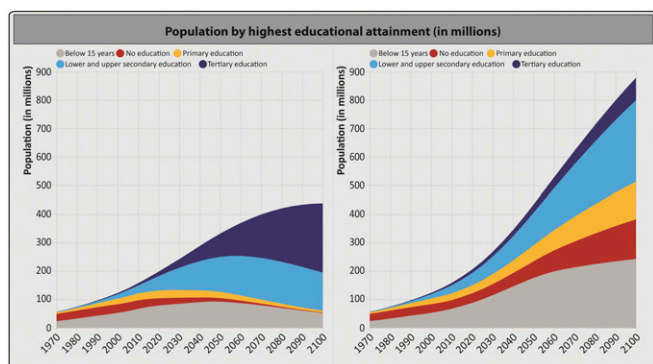


Fig. 5. SSP1 (Left) and SSP3 (Right) for Nigeria. Data from Klingholtz and Lutz (11).

fertility associated with meeting the goals, this is significantly lower than the world population of 11.2 billion projected for 2100 by the United Nation’s medium variant and the 9.0 billion resulting from the middle-of-the-road scenario shared socioeconomic pathway (SSP)2, discussed next.

Alternative Scenarios for the 21st Century

These insights and methods of multidimensional population dynamics are also reflected in a new set of global scenarios developed by the international climate change research community to comprehensively address the socioeconomic determinants of climate change mitigation and adaptation. These SSPs are based on five different storylines about future developments in all countries of the world in terms of different demographic, social, economic, and technological dimensions (65). The human core of the SSPs consists of population scenarios by age, sex, and six different levels of education (66). Fig. 4 shows the global-level results in terms of total population size of three of the scenarios: SSP1, reflecting rapid social development; SSP2, reflecting middle-of-the-road assumptions; and SSP3, showing a scenario of stalled development.

In the following, I will only focus on the results for two big countries, Nigeria and Pakistan, and contrast the SSP1 and SSP3 scenarios. Nigeria currently has a population of around 180 million, which is still growing at a rate of over 2.5% per year because of an average fertility rate of around six children per woman and a very young age distribution. As Fig. 5 indicates, almost half of the population is below the age of 15 and 40% of the adult population has never been to school. The SSP3 narrative of stalled social development—including stalling school enrollment and little progress in basic health care, including reproductive health—results in continued high population growth to reach a population of 880 million people by the end of the century. Given the current civil war in parts of the country, this is a not implausible scenario, which actually is even lower than what the United Nations in 2012 projected as the most likely future of Nigeria. If, on the other hand, recent improvements in school enrollment of girls in most of the country continue and general socioeconomic developments take off quickly, as expected by some observers, then the population might only increase to half that size. And the education distribution during the second half of the century would resemble that of Europe today, with high proportions with secondary or tertiary education. This finding could imply that in many other important respects, ranging from income to the quality of institutions, Nigeria in 50 y could possibly enjoy similar standards as Europe today. In the case of Pakistan (Fig. 6), the contrast between the two scenarios implying very different futures is comparable.

Which of these two very different future scenarios is more likely? Both Nigeria and Pakistan have fundamentalist groups that directly attack any efforts to educate girls. The name of the Nigerian insurgent

group Boko Haram means in translation “education is sin” or “books are sin.” In Pakistan, Malala Yousafzei was shot in the head at the age of 14 by a group related to the Taliban simply because she wanted more girls to go to school. Resisting modern education, which is regarded as the source of all unbelief, is often at the heart of the rejection of the West by such groups: this points at a possible self-reinforcing vicious cycle driven by the link between population growth and lack of female education. Religious fanaticism often recruits its followers in places where many people live in poverty, where there are low levels of education and high population growth. Hence, the rapid expansion of female education that would be necessary to fight the latter can be seriously hampered by fundamentalist movements that in turn benefit from high population growth, low education, and the resulting unemployment. Given these forces, further progress in such countries as Nigeria and Pakistan is by no means guaranteed. If the spread of education stalls, the population continues to grow rapidly, and political insecurity hinders investment and the creation of jobs, this can lead into a bleak future that will not leave the rest of the increasingly globalized world unaffected (11).

Education and Adaptation to Climate Change

Recently, in the analysis of climate change, the attention has shifted from an earlier almost exclusive focus on mitigation to adaptation that will be necessary when coping with already unavoidable changes of the climate. However, much of the ongoing research in the field superimposes projected biophysical conditions onto present-day socioeconomic conditions (67), when we know that societies are also changing over time in dimensions, such as public health capabilities that are essential for their adaptive capacity. Disregarding such future social change is misleading. It has been demonstrated recently that education is a key determinant of differential vulnerability, both at the individual and societal level (68). Hence, the demographic metabolism model and the associated SSP scenarios are an effective way for forecasting societies’ future adaptive capacities to climate change (39). When contrasting the SSP1 and SSP3 scenarios for the rest of the century (69), it was recently shown that because of the educational expansion under the rapid social development path in SSP1, disaster mortality will be much lower—even in the case of increasing climate related hazard—than in the SSP3 scenario, where underinvestment in education leads to high population growth and heightened vulnerability. Given the uncertainty about the precise manifestations of climate change in specific areas, there is a strong case to be made for general empowerment through education, which increases human and social capital to flexibly and effectively react to upcoming challenges rather than investing in massive concrete infrastructure projects. The implications of these findings for the allocation of resources, such as the pledged \$100 billion per year of the Green

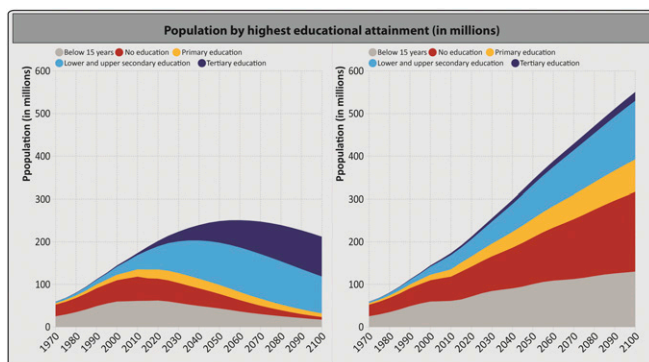


Fig. 6. SSP1 (Left) and SSP3 (Right) for Pakistan. Data from Klingholtz and Lutz (11).

Climate Fund to help developing countries with adaptation, are significant. The subtitle of the relevant paper in *Science* succinctly summarizes this in “Fund more educators rather than just engineers” (69).

More generally, for the interactions of humans with environmental change, education has been shown to matter for behavioral changes necessary to mitigate human impacts, such as changing behaviors in terms of choosing greener technologies, switching to public transport, or recycling waste (39). Because education improves knowledge, understanding of complex information, efficiency in allocation of resources, and capacity to plan for the future (70, 71), it is conducive for making better choices at the individual and societal level that will make a transition toward sustainability more likely.

Dematerialization in Aging and Shrinking Populations

A recognition of the world’s increasing ecological problems has also triggered discussions about alternatives to the currently dominant neoclassical economic growth model. This goes back partly to the thinking of classic economists, such as Adam Smith and David Ricardo, and their concept of a steady-state economy, and has also led to the rather young field of ecological economics and the notion of “degrowth.” Critics of the steady-state economy, on the other hand, argue that technological development and market mechanism will be capable of overcoming resource scarcity, pollution, or the effects of continued population growth.

The combined effects of population growth (P), affluence (A), and technology (T) on environmental impact (I) has sometimes been expressed through the “I = PAT” identity. Called the Ehrlich-Holdren or Kaya identity, it lends itself to efforts of quantification of the shares of the contribution of the individual components. The decomposition literature based on this identity has, however, been inconclusive because of the fact that the three components tend to work in different directions, are not independent from each other, and not all consumption can be meaningfully attributed to individuals. In particular, it has been pointed out that households and not individuals should be taken as the consuming units and that the consumption or impacts of big companies or the military cannot be meaningfully attributed to individuals. But despite some of these problems, the literature mostly agrees that population change and change in consumption patterns are both relevant aspects, even though the latter tends to dominate the picture (72).

If the fertility transition around the world continues, in the very long run world population will peak and eventually start to decline (68). Because of uncertainty about fertility stalls in some African countries, which are likely a late consequence of education stalls associated with structural adjustment programs in the 1980s (73), there have recently been some upward adjustments in long-term population projections. However, recent calculations of the impact of meeting the SDGs (64) and an accelerated fertility decline in Africa (74) show again a much lower path of population growth. Very long-run scenarios assuming that the global average fertility by the end of this century will be at the average European level of today—with East Asia already being below that level—will result in total world population sizes of 2–6 billion in 2200, depending on the maximum life expectancy that is being assumed (75). Based on this, I had titled an editorial for the Royal Statistical Society “Towards a world of 2–4 billion well educated and therefore healthy and wealthy people” (76), and based on my more recent work, cited above, I could now add “. . . that would be able to cope well with the consequences of already unavoidable climate change.”

This priority focus on education and health in efforts to dematerialize further increases in human well-being also holds for highly developed and rapidly aging societies.

In 2014, eight European Academies coordinated by the German Leopoldina issued a joint policy statement about the challenges and opportunities for aging societies. This consensus statement explicitly points at the sustainable development

implications of these trends, stating: “Population change in the 21st century is to be placed in the context of consumption and environmental protection within Europe as well as around the world. Economic and social systems need to be reorganized in a way so as not to depend on continued increases in non-renewable material consumption. Europe may take these population changes also as a starting point towards furthering investment in non-material, high quality growth” (77). The statement also stresses that in a globalizing world, with an economy that is increasingly technology-based, the cognitive resources of societies will be a key factor in international competitiveness, and hence for maintaining the wealth of European economies. It also stresses that well-being not only encompasses physical health but importantly also cognitive functioning and mental health. In these policy recommendations for advanced and rapidly aging European societies—perhaps surprisingly to some—emphasis is put on the importance of education for all, including eradication of functional illiteracy and the development of continuous education (lifelong learning). Hence, this eight academies statement clearly identifies universal education and health as priorities for Europe in the 21st century.

My Personal Learning Curve

Everybody has a personal bias when it comes to setting priorities and for scientists there may also be a disciplinary bias. I certainly did not start out as an education lover. Quite the opposite: the very first piece that I published in a student journal had the title “Elementary school: A crime on children” (78), addressing the many frustrations I had experienced in my old-fashioned primary school. I studied philosophy, theology, and mathematics, and then—inspired by the 1972 report of the Club of Rome (79)—decided to focus on statistics and systems modeling, which seemed to offer the most appropriate tools for comprehensively studying the future challenges of humanity. For a sharper disciplinary focus, I went for the mathematics of groups of people: that is, demography. Later I had the opportunity to join the International Institute of Applied Systems Analysis in Austria, an institute that had been set up in 1972 to do such comprehensive global systems modeling.

To better understand the complex dynamics of population–development–environment interactions in my first major independent study, I developed a systems model for the island of Mauritius, a microcosm with good historical data. In the 1960s Mauritius had been desperately poor and served as a textbook example of a country trapped in the vicious circle generated by rapid population growth, extreme poverty, limited land, and environmental degradation, and to top it off, was frequently hit by ferocious cyclones (80). In the 1970s the island experienced a record breaking fertility decline from over six to around three children in just a decade, and came out of poverty mostly through an export-oriented textile industry, which through the associated heavy water pollution, was about to seriously harm the unique coastal ecosystems on which the incipient luxury tourism depended. In 1990 my team built detailed models of the interacting water, land-use, population, and economic systems to address these future challenges and to reconstruct how Mauritius had escaped the poverty trap (18). Unlike other models at the time, ours also included the educational composition as well as social, political, and institutional dimensions. Through extensive sensitivity analyses of alternative histories and futures, we tried to find out which policy variables were the most important in triggering lasting improvements in the well-being of the entire population. This resulted in a decisive insight: no matter how we twisted the model or defined alternative scenarios, the key driver of the past success always turned out to be female education (more than male) and family planning, and the key driver of future economic growth and environmental preservation was further investment in human capital. Fortunately, Mauritius continued to follow this path and today is one of the most developed countries in the entire Africa region,

based not only on up-scale tourism but more so on high-tech industry and services, quite a way from the “hell on earth,” as it was called in the 1960s.

The 1994 book summarizing these findings concludes: “With respect to international development priorities, this suggests a radical change of emphasis. Less attention should be given to large-scale projects . . . (but) to investment into human resources—education, health and family planning. . . . It is a very robust policy that may only show modest immediate results, but a great payoff in the long run” (18). This was my systems-analysis-based conversion from seeing basic education as a nuisance to seeing it as the key prerequisite for successful human and sustainable development.

Over the following two decades, the robustness of this finding was tested empirically in many more case studies around the world (81), and I did not find a single example in which empowerment through basic education was not among the very top factors that mattered for many of the other desirable outcomes. The only competitor for first place was basic health, with income typically coming further down. And once you consider in your model education as a possible driver, it comes out dominating even in fields that seem to be far away from social development. Pascal Lamy, former head of the World Trade Organization, calls education the single most important factor in international trade policy.*

Why have most other researchers not reached the same conclusion, particularly because, globally, surveys show that the general public clearly prioritizes education and health (82)? A plausible answer could be that many analyses do not even include education in the model, and consequently cannot come to the conclusion that it is the key factor. A good example for this can be found in the mainstream work on vulnerability to natural disasters where education has typically not been on the table as a relevant variable to be studied. If education data are collected and it is properly included in the model, the results typically show that it is more important than income or other conventionally considered factors (68). The results of the many studies conducted in different parts of the world show that more education and better education does not necessarily and linearly always lead to success, but it is an indispensable prerequisite and significantly raises the chances for success in terms of sustainably increasing human well-being.

Science and Policy Implications

As of January 2017, I have been appointed by the United Nations to be a member of a “Group of 15 Independent Scientists” charged with monitoring the implementation of the SDGs and drafting the quadrennial Global Sustainable Development Report to be presented to all heads of state and government at the General Assembly in 2019, without preceding government negotiations and agreement. This presents an innovation in United Nations procedures that finally gives independent science an independent say. It is a great opportunity and a great challenge. One of the main tasks will be to not look at the SDGs in isolation but study their synergies and possible contradictions. We will also have

to address the question of SDG priorities from a science and policy perspective.

It terms of policy priorities, it is evident that currently not all 17 SDGs receive equal attention or funding. Because of the bottom-up somewhat unsystematic nature of the 17 goals and 169 targets, it is difficult to argue that they all should receive equal funding. Actually, in this contribution I argue for priority funding for basic education and basic health. Although basic health has seen strong increases in international funding—not least by private sources, such as the Gates Foundation—basic education is woefully underfunded, particularly in countries affected by conflict. The Organization for Economic Cooperation and Development statistics of all international development assistance show that over the past years, a mere 2–4% has been spent on basic education (11). It is important to stress that spending alone is not enough, if the funds are not effectively allocated and consequently do not lead to better learning outcomes, as has partly been the case in the past. The science-based case presented here would strongly support a massive new global effort for universal basic education, leading to effective learning outcomes.

What all of the SDGs have in common is that they require changes in human behavior in one way or another. And such changes in the end need to happen in the human mind. They are conscious processes of making choices with a view to the future. Luther, 500 y ago, made his choices based on religious insights and convictions. The world today is immensely more complex and rapid changes in society and human impacts on the environment make it necessary to explicitly and systemically think about the future. Because this future will be different from today, it cannot yet be experienced with our senses. We need to be able to abstractly think the counterfactual. If we do not think ahead and do not consider the necessity of maintaining functioning natural life support systems, we or our decedents will likely hit a wall and suffer the pains. Thus, it is in the end down to abstract cognitive processes in our brains that combine our insights about where current trends will get us and what future we prefer, that results in actual behavior. For these choices to be reasonable, and to our own and our societies’ benefit, we need as most fundamental prerequisites to have a healthy body with a functioning brain (*sanitas*), as well as a brain that is trained to think abstractly and educated to structure information in a meaningful way (*schola*). To secure these prerequisites requires some initial efforts, but then the good news is that brain power is one of the few resources that are not exhausted by being used: quite the opposite, it is strengthened by being used.

Please note: a more extensive treatment of the topics presented in this article is given in a forthcoming popular science book, *Education First: From Martin Luther to Sustainable Development*, by Wolfgang Lutz and Reiner Klingholz (83).

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