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The ethics of knowledge production and the problem of global knowledge inequality

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Abstract
Given demonstrated global knowledge inequality, this article attempts to draw out the connection between tertiary education and research (TER), economic development and infrastructure, and human development. We first explore the connection between knowledge and economic development by tracing a short history of the emergence of knowledge in economic analysis and by introducing the concept of a 'knowledge economy'. The World Bank's 'Knowledge Assessment Methodology' (2000) attempted to evaluate such 'knowledge economies' through a number of proposed variables. We describe relationships between such TER-variables, economic development, and infrastructure building, especially in the shift towards digital economies. We will show that there is a tangible, negative human impact from disparities in knowledge production, and significant improvement in human welfare when knowledge production capacities improve. Finally, we will illustrate how these relationships play out in two case studies, in Montenegro and Bangladesh.

Keywords
development ethics, digital economy, global knowledge inequality, human development, knowledge economy

> "The confinement of the knowledge economy has momentous consequences. Today it has become the single most important cause of both economic stagnation and economic inequality."[1]

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1. Introduction

Knowledge production directly influences the economic prospects of a country. This has been well documented, and knowledge—through markers such as number of years of education, literacy, and so on—has been factored into the analysis of economic development since the days of classic economic theory. Today, the Human Development Index—a measure to assess the development of a country, HDI—includes an Education Index in its parameters, measuring the expected and mean years of schooling.

Recent global reports have drawn attention to the disparity in knowledge production between the more developed countries and the less developed ones.[2] This disparity cannot be explained away in a circular fashion, by claiming that the disparity exists *because* of low economic development. Political theorist Roberto Unger describes the current state of affairs as a knowledge economy that is 'insularly distributed at the fringes in more developed countries'. This distribution of the participation in and benefits of the knowledge economy among the few, he asserts, supports ongoing economic stagnation and inequality.[3] This inequality also forces those from less developed countries to live diminished lives', on account of the increased globalization that connects us all together.[4] This impoverishment, at the level of tertiary education and research (hence, TER), is rooted in historical injustice, and has difficult implications for future generations of such countries if left unacknowledged and unsupported. Unger notes that asking less developed countries to take the long road of economic development (i.e., through the mass industrialization phase that many more developed countries have passed through) is premised on the idea that 'all economies must follow the same relentless evolutionary sequence, rehearsing in a later historical period as their future the past of the economies that have overtaken them'.[5] He argues that this is unfeasible, since the most advanced practice of production (the knowledge economy) has changed globally: developing countries have no other realistic option but to adopt it.[6] This is also reflected in UNESCO's 2021 Science Report.[7] Thus, the disparity in knowledge production affects not only the current state of development of the Global South, but also its future.

2. Global knowledge inequality

This article is particularly concerned with global knowledge inequalities in TER. This includes disparities in knowledge production in terms of patent counts, publications, enrollment in tertiary programs, researchers, and the protection of intellectual property. These relevant factors have been selected from the popular Knowledge Assessment Methodology framework developed by the World Bank from 2004 to 2008 to support countries' transition to being *knowledge economies*.[8]

Knowledge inequalities are identifiable from recently available data. Globally, 19% of tertiary students are enrolled in short-cycle programs, 68% in bachelor's degree programs, 11% in master's, and 1% in doctorate programs. Of the gross enrollment in tertiary programs, only **8%** are from **low-income countries.**[9] The disparities in knowledge production globally are also demonstrable through gross domestic expenditure on research and development (GERD), the number of researchers in a country as a percentage of the global set, and in terms of tertiary enrollment numbers.

Between 2014 and 2018, the **GERD per researcher** for lower-middle income and low-income countries dropped sharply.[10] Their combined **share of global researchers** in 2018 was **only 8.56%**.[11] Low-income countries account for only **0.2% of the world's researchers** even though they have had the fastest growth in researcher density (upwards of 36%) since 2014: brain drain remains a chronic problem for many countries with low or stagnating research expenditure.[12] (Brain drain occurs when highly educated individuals migrate to other countries to pursue better professional opportunities. Thus, receiving tertiary education does not necessarily translate into research capacity unless other socio-economic conditions within the country allow for the smooth transfer of graduates into research positions.)[13]

The disparity of global knowledge inequality is more than that in Gross Domestic Product (GDP). G20 nations, comprising the EU and 19 highly developed Western countries, accounted for **82% of worldwide GDP** in 2018. However, in terms of scientific research publications, these nations accounted for roughly **90% of all worldwide publications** in 2019. Only **12.3%** were from **lower-middle-income and low-income countries**, even though this represented a welcome increase from the 8.6% share they had in 2015. The **G20 countries** also held **96.5% of all patents** in 2019.[14] If one were to exclude the G20 countries as well as other high-income countries, then in 2019, the rest of the world produced only 0.4% of global IP5 patents, a reduction from 2015.[15] Thus, there is demonstrable knowledge inequality in the world in terms of TER. This inequality sustains or exacerbates other forms of inequality, especially poverty.

In addition, these disparities undermine the emergence of knowledge economies in the Global South. A **knowledge economy** is an economic system in which the production of goods and services is based principally on knowledge-intensive activities that contribute to advancement in technical and scientific innovation. It describes the contemporary commercialization of science and academic scholarship. In knowledge economies, innovation based on research is commodified via patents and other forms of intellectual property. Knowledge-related industries represent a large share of the activity in most highly developed countries. Thriving knowledge economies will depend on skilled labor and education, strong communications networks, and institutional structures that incentivize innovation. Following Unger, the Global South must both achieve greater knowledge production to improve its trajectory of conventional economic development and move toward achieving knowledge economies.

3. What we want to do

Given the demonstrated knowledge inequality, this article attempts to draw out the connection between TER, economic development and a country's infrastructure, and human development. This article is an exercise in demonstrating the tangible impacts of theoretical training and expertise on everyday life on a mass scale. To make these connections, we first explore the connection between knowledge and economic development. We do this by tracing a short history of the emergence of knowledge in economic analysis, focusing especially on the World Bank's Knowledge For Development (K4D) work in the 2000s. After explicating the four pillars of a knowledge economy, we take up the Knowledge Assessment Methodology (KAM). KAM is a diagnostic and benchmarking tool that provides a preliminary assessment of countries'/regions' readiness for the knowledge economy. There are 80 possible variables that economists Derek H. C. Chen and Carl J. Dahlman identified. We selected factors from the KAM list of possible variables, choosing the factors that best correspond to TER. These are: tertiary enrollment, science and engineering enrollment ratio (as a percentage of tertiary level students), researchers in research and development, researchers in research and development per million of the country's population, research collaboration between companies and universities, scientific and technical journal articles, scientific and technical journal articles per million people, patent applications granted by the USPTO, and patent applications granted by the USPTO per million people. We will describe relationships between such factors and economic development and infrastructure building, especially in the shift towards knowledge economies and digital economies. Finally, we will show that there is a tangible human impact between knowledge production capacities and human welfare.

4. From knowledge to economic development

For a quick economics lesson: when economists talk about productivity, they are talking about the ratio of aggregated output units to aggregated input over time. This connection is often summarized by a *production function* (the mathematical kind), where the productivity (often, GDP) is related to physical capital, labor, and the efficiency of transforming the inputs into outputs.[16] Kenneth J. Arrow's 1962 article 'The Economic Implications of Learning by Doing' was one of the early moves in separating knowledge as a factor of productivity in traditional economic analysis of labor and capital. He noted that 'even students subject to the same educational experiences have different bodies of knowledge, and we may therefore be prepared to grant […] that different countries, at the same moment of time, have different production functions even apart from differences in natural resource endowment'.[17] Peter Drucker popularized the term 'the knowledge economy' in 1969 by using it as the title of a chapter in his book *The Age of Discontinuity*.[18]

The world saw a rapid increase in the exchange of information with the introduction of digital technologies in the latter half of the twentieth century. These new technologies promised to change the way we thought of economic productivity and its factors. In 1996, James Wolfensohn, the president of the World Bank, announced a 'Strategic Compact', steering the World Bank's course towards being a 'Knowledge Bank' by the turn of the millennium. The World Bank commissioned many economists and researchers to develop the conception of the knowledge economy, with peak publishing occurring between 2002 and 2009. Carl J. Dahlman was the project lead for the Knowledge For Development (K4D) Program. His team ushered in the era of the 'knowledge economy' in international policy and development goals. They proposed that knowledge contributes to economic productivity in ways that would remain sustainable in the long run, unlike traditional factors which were subject to diminishing returns.[19]

Dahlman and Derek Chen's 2004 article 'Knowledge and Development: A Cross-Sectional Approach' aimed to assess the effects of knowledge on economic growth. They asserted that '[k]nowledge [could] become the main engine of growth if [a country's] economy satisfies certain preconditions'.[20] These preconditions included (a) a sufficiently equipped working population, (b) high domestic innovation and the adoption of new technology, (c) an established information and communications infrastructure, and (d) an economic and institutional regime that would allow for the propagation of knowledge.[21] All four of these, their research found, led to '[…]statistically significant positive effects on long-term economic growth[…]': increasing the average years of schooling of a population in one case and an increase in the number of patents filed in another case were both correlated with an increase in average annual economic growth.[22] These four preconditions, modified and expanded slightly, were accepted by the World Bank as the 'pillars' of a knowledge economy.[23]

Chen and Dahlman asserted that '[S]trengthening the [four] pillars of the knowledge economy [would] lead to an increase in the quantity and quality of the pool of knowledge available for economic production […which would…] consequently increase productivity and thus economic growth'.[24] This, they said, was in line with the existing literature, which agreed that the education level of the working population impacted the aforementioned efficiency of economic productivity, along with innovation, the institutional atmosphere (in terms of stability and protections for said innovation), as well as extant information and communications technologies.[25] Thus, Dahlman went on to define a knowledge economy as '[…]one that uses knowledge as an engine for economic growth across the four pillars of the knowledge economy[…]' in his first newsletter as project lead of the World Bank's Knowledge For Development (K4D) Project in 2004.[26]

The K4D Project was initiated to assist countries with transitioning from their traditional economies to knowledge economies in order to prevent countries from falling behind as the 'knowledge revolution' swept the globe. It would do this by analyzing the country's status via the Knowledge Assessment Methodology and use the results to inform strategies towards strengthening the four pillars described above. The World Bank went on to develop multiple indices to try to capture the state of a country in terms of its readiness for said transition, called the Knowledge Economy Index[27] and the Knowledge Index.[28] These indices were abandoned in 2012 as the global turn towards 'digital economies' became clear. In 2012, there seems to have been a pivot toward focusing on innovation, with the introduction of the Global Innovation Index. The Global Innovation Index included knowledge production, impact, diffusion, and workers in its analysis. In 2017, the United Nations Development Program (UNDP) launched the Global Knowledge Index (GKI), a '[…]summary measure for tracking the knowledge performance of countries at the level of seven areas, namely pre-university education, technical and vocational education and training, higher education, research, development and innovation, information and communications technology, economy and the general enabling environment'.[29] The GKI is an attempt to find a more evidence-based linkage between development and knowledge, covering 138 countries and 199 indicators.[30]

Most attempts at including education in productivity analysis have focused on or emphasized maternal education, early education, and primary education.[31] This article attempts to focus on the knowledge inequality at the TER levels. It is these kinds of theoretical and technical training that more directly allow for a different kind of incorporation of knowledge into economic activity.[32] Political theorist Roberto Unger observes, in light of the rapid progression towards 'digital economies', that there is a gnawing inequality in the distribution of the goods that technological advancement has brought. He asserts that these gains have been 'insular' to the so-called developed countries, and that this situation undermines economic growth and exacerbates economic inequality.[33] Dahlman and his fellow researchers Sam Mealy and Martin Wermelinger, similarly, raise concerns about the risk of the increasing digital gap between developed and emerging economies. They recognize the current digital revolution as promising a better future for economies and livelihoods, '[…]predicated on the ever-increasing pace of technological innovation and diffusion'.[34] These digital technologies are reshaping economies by lowering certain costs of production, increasing efficiency, expanding or creating markets, providing economic opportunities in more sectors, and developing improvements to existing technologies.[35] The authors noted the difficulty of defining the concept of the digital economy, calling it an '[a]malgamation of several general purpose technologies (GPTs) and the range of economic and social activities carried out by people over the Internet and related technologies'.[36] A key factor in digital economies is the skilled labor available in the working population.[37] Digital economies need trained engineers to 'build, maintain and service' (a) the equipment used to send and receive data, (b) data storage systems, and (c) other technology that could be embedded with a digital network to 'facilitate the Internet of Things'.[38] Such economies also require specialists in computer science, user interfaces, and user experience, who would be responsible for algorithms and systems required for users to operate the digital infrastructure.[39]

It is important to note that the exponential growth of digital and similar new technologies has not occurred in a siloed way, vertically, or through a single engineer or innovator's skill. The advances in different fields of computing, energy, biology, and material science have happened parallel to one another and informed one another: advanced economies now require skilled specialists who are *interdisciplinary* as well.[40] The recent COVID-19 vaccine development strategies involved global partnerships in research and development that would not have been possible without such specialists. Recent research from South Africa has indicated that artificial intelligence (AI) can be employed strategically towards the attainment of some of the Sustainable Development Goals (SDGs), 'particularly poverty reduction in areas of relevant data collection through poverty maps, its ability to revolutionize agriculture, education, as well as the financial sector through digital financial inclusion'.[41] AI and machine learning are being applied to a variety of specialized fields, including medicine, transportation, climate modeling, and inventory management. Finally, as per the 2022 SDG Report, higher-technology industries have been seen to be more resilient in crises than lower-technology industries, in some contexts, such as the COVID-19 pandemic.[42]

Thus, digital economies require novel developments among the working population of a country. An important set of roles is that of the 'specialists', some of whom have been just described.[43] 'Their main job is to develop, provide and maintain the digital equipment, networks, or services for customers. They need to possess the knowledge to operate and maintain info-communications technology systems'.[44] These roles need training and expertise that can only be gained via tertiary education.[45] This level of training, say Dahlman, Mealy, and Wermelinger, could be gained domestically—by investing in education, training, and research—or by creating the conditions for foreign experts to contribute to the country's digital economy. They note that 'although building an indigenous pipeline of talent requires investment and time, it results in a more stable talent pipeline'.[46] Thus, TER proves to be essential to economic development in the twenty-first century, particularly in light of the digital revolution.

The knowledge economy framework has not entirely disappeared: it still remains true that, outside of the digital economy, the turn to this new way of thinking about long-term sustainable development (the introduction of knowledge as a prominent factor in productivity) 'presents significant opportunities for promoting economic and social development, thereby reducing poverty'.[47] It remains important for low-income countries to be attentive to their productivity (GDP) since it remains significantly correlated with human development indicators (HDI).[48] For instance, the literature shows that 'each additional year of education produces a private (i.e. individual) rate of return to schooling of about 5–8% per year, ranging from a low of 1% to more than 20% in some countries. Globally, the returns to tertiary education are highest, followed by primary and then secondary schooling […]'[49]

5. From economic development to human flourishing

The relationship between economic development and human flourishing is a complex one.[50] Simply put, the GDP per capita of a country fails to account for all that determines whether a population is flourishing: it is a monetary measure of the market value of goods and services produced in a year, divided by its population. Thus, it is a purely economic factor. However, it does not paint a clear picture of whether a country is thriving. The Human Development Index was developed in 1990 to account for more factors—specifically life expectancy, average years of education—besides average income. The HDI measures average achievement in health, education, and standard of living dimensions. The length and quality of human life were introduced into the measure of the development of a country in this way. Nonetheless, in general terms, it is clear that economic development contributes to health, longevity, reduction in basic forms of hardship, and increased opportunities of various sorts.

A 2006 endeavor to explain the historical decline in human mortality rates admitted that making clear causal connections between mortality rates and socioeconomic factors was difficult, given the complex and particular (as opposed to universal) relationships between the latter and quality of life. In general, it is not disputed that poorer countries have lower life expectancies than richer ones, though those numbers have improved over time.[51] However, the authors affirm that '[k]nowledge, science and technology are the keys to any coherent explanation', pointing to advances in understanding disease, public health administration, innovations in medical procedures, and the development of pharmaceuticals.[52] They suggest that 'greater speed of introduction of new health-relevant knowledge and technology will tend to raise the health gradient'.[53] They note that 'educational differences (like other forms of power differences) will maintain a gradient in health whenever there exists a mechanism or technology that more knowledgeable and educated people can use to improve their health'.[54] Thus, there are specific circumstances where TER is directly linked to better human health.

However, more generally, we see that TER is tied to poverty and economic development. Poverty is considered a social determinant of health, and thus economic considerations are intimately involved with the length and quality of one's life.[55] In fact, life expectancy showed a strong correlation with gross regional domestic product per capita in a large-scale study in Indonesia between 2010 and 2018.[56] A 2019 study in the same country further showed not only that the presence of medical professionals was positively correlated with life expectancy, but more generally that poverty was negatively correlated with it.[57] When it comes to infant and child mortality, the numbers are overwhelming. The World Health Organization (WHO) states that **16,000 children die every single day** before reaching the age of five: **children** from the **poorest 20% of households are nearly twice as likely to die** than their peers from the richest 20% of households.[58] In part, this is because having access to medical care is essential in ensuring prolonged life and quality of living. When it comes to childbirth, especially, increasing the number of skilled medical practitioners is negatively correlated with maternal, infant, and childhood mortality. A recent study from Brazil shows **7.08 fewer infant deaths per 10,000 per one physician added per 10,000 people.**[59]

Other factors related to development play a major role as well. For example, diseases transmitted by vectors can be reduced through **sanitation** and **water management** interventions. The WHO notes that bad sanitation infrastructure can lead to the proliferation of the *Culex* mosquito, which transmits filarial parasites to humans. Storing water safely can keep the *Aedes aegypti* and *Aedes albopictus* mosquitoes which transmit dengue and chikungunya to humans mainly in urban areas at bay.[60] Water management and sanitation interventions like piped water, sewers, and chlorination have been linked to a drop in infant mortality, seen as early as the late nineteenth and twentieth centuries in Finland.[61]

We see how economic development contributes to human welfare in many other contexts as well. Access to modern energy in educational setups improves the quality of education, which leads to better education completion rates and provides lifelong benefits.[62] A study in Indonesia showed that electricity infrastructure had a greater influence on human development than other types of infrastructure. It found an HDI increase of 0.2% for every 1% increase in the proportion of households with electricity.[63] For persons living in countries like Nepal, access to infrastructure, such as roads, drinking water, and irrigation facilities, is essential to human well-being because of the country's particular topography. A study on infrastructure and human well-being in Nepal in 2017 'determined that the perceived impacts of access to infrastructure on human well-being is higher in more remote areas'.[64] In terms of potable water and sustenance: the SDGs Report 2022 states that the **quality of water for at least 3 billion people is undetermined** because of a lack of monitoring.[65] Further, the report notes that **13.3% of the world's food is lost** after harvesting before it is sold at markets,[66] demonstrating a need for better **transportation** and **storage** infrastructure and technologies.

Viable infrastructure relies on personnel with training and expertise. As noted in the discussion about the MDGs, the UN has observed a **dearth in quality data collection, management, and statistical analysis** in many countries. These skills are vital in order to provide us with a clear picture of inequalities such as the ones this article has set out to describe. Each of the aforementioned connections between economic development or infrastructure and human development assumes the availability of skilled labor and advanced technology. It is only through TER that such capacities can be developed and sustained towards achieving the ambitious SDGs by 2030.

6. Two case studies

6.1. Case study 1: Montenegro

A key example of how TER translates into economic development, which then results in positive outcomes for human welfare, can be observed in the case of Montenegro's response to the COVID-19 (coronavirus) pandemic. On March 17, 2020, Montenegro became the last country in Europe to record a positive COVID-19 test.[67] As a developing country lacking in both diagnostic equipment and expertise, Montenegro faced immediate challenges in responding effectively and rapidly to the pandemic. Furthermore, as a small, developing country with a highly tourism-dependent economy, Montenegro faced immanent pressure to reopen the country's borders without risking further endangerment to its citizens, making it especially pertinent to 'achieve herd immunity in their populations as early as possible and hasten the end of the pandemic for their citizens'.[68] Achieving this would be especially difficult given that, not being part of the EU, Montenegro did not have early access to vaccines, and did not receive its first vaccines until March 2021, with aid from the COVAX initiative.[69] In light of these conditions, accurate and early diagnosis, as well as mitigating the spread of coronavirus, became tasks of utmost importance.

In 2015, the World Bank-funded Higher Education and Research for Innovation and Competitiveness (HERIC) project invested in Montenegro's Institute of Public Health and the University of Donja Gorica, in the form of RT-PCR machine[70] for the former, and equipment for 3D printing, scanning, and modeling, and mechanical testing and materials for the latter.[71] Provided with these technologies, it was then possible for Montenegro to detect COVID-19-infected patients quickly and efficiently, as well as produce personal protective equipment for medical staff. In these institutions, these investments facilitated innovation in quality and relevance of higher education and research/development since access to this new technological infrastructure created more educationally robust environments for academic and scientific learning/training. This transformation in the space of knowledge production produced tangible outcomes for Montenegro's economy, in the forms of job creation and increased human capital. Thanks to the accessibility of these technologies and the need for specialized training in their use, Montenegro was capable of rapidly generating and deploying highly educated and highly skilled individuals in the effort to mitigate the spread of COVID-19.

In this case study, it becomes apparent how investment at the level of tertiary education—in the form of diagnostic, educational, and research-focused infrastructure—leads to increased opportunities and enrichment in learning environments for the academic and scientific communities. The result is an increase in the number of medical and technical workers with advanced levels of education and training, such as researchers and faculty at the Institute of Public Health and the University of Donja Gorica Thus, investment in higher education institutions translates into investment in increased opportunities for knowledge production at the level of higher education. In turn, the availability of the technology/equipment necessary for particular job positions, coupled with the increased demand for knowledgeable workers, both creates jobs and increases the demand for jobholders—facilitating economic development. Finally, the increased number of highly skilled scientists, medical workers, and other relevant professionals available to treat and protect the population leads to overall improvement in infectious disease management in response to pandemic-related threats, and therefore, in human welfare.

6.2. Case study 2: Bangladesh

Another pertinent example of the TER to economic development to human welfare relationship that we have identified can be observed in the case of Bangladesh's efforts to provide safe drinking water for its citizens. In Bangladesh, poor urban areas often lack adequate infrastructure for water sanitation and distribution, and even where functional treatment plants exist, 'drinking water is often re-contaminated by sewage as it travels in unpressurized pipes to water collection points in different parts of the city'.[72] Rahman et al. (2022) state, 'Drinking water is often contaminated, and hence, water-borne diseases are common in Bangladesh. None of its city water supplies are reliable, and hardly any person would like to drink mains water without further in-house treatment such as filtering or boiling'.[73] According to the World Bank, this issue is particularly dangerous and deadly for children, amongst whom diarrheal diseases like typhoid and cholera result in 800,000 deaths per year globally.[74]

As part of the effort to improve water quality, the World Bank's Strategic Impact Evaluation Fund (SIEF) conducted a double-blind study in low-income communities in Dhaka and Tongi, to determine whether the installation of automated chlorination systems at shared water collection points would result in improvements in child health. In Dhaka, children in the treatment group demonstrated a 38% reduction in diarrhea, while children in the Tongi treatment group demonstrated an 18% reduction in diarrhea.[75] Furthermore, the prevalence of *E. coli* contamination at the point of water collection dropped from 64% to 15%, suggesting such interventions can reduce child disease/death in low-resource areas.[76] The study thus demonstrates the importance of safe, accessible water at community taps for producing tangible positive outcomes for child health, with implications for reducing the rates of childhood disease/death.

While the treatment system utilized in the study was 'passive' insofar as 'the chlorine is automatically added to the water',[77] the devices require regular maintenance, nonetheless, by personnel with at least some training.

The research team employed a full-time engineer to monitor the devices and ensure proper function,[78] but following the study's conclusion, continued installation monitoring would have to be overseen by locals, such as engineers or trained community members.[79]

However, studies have indicated that it is difficult to motivate communities to adopt and maintain new technologies: less than 30% of households in Dhaka used point-of-use products even when they were provided free of cost.[80] One option to achieve the success of widespread implementation of water chlorination infrastructure would entail improved community education in safe water practices and improved engagement in device monitoring. A second approach would involve a different form of knowledge-informed practices: Haque and Sharif (2021) propose that the solution to these challenges can be reached through investing in better environmental engineering programs—for example, to include a community-based approach: 'The community-based approach in dealing with the environmental issues can help the engineers to understand the environmental problems from the community level at its core. By interaction and active engagement with the citizens these problems can be alleviated, not only by the technical components, but by the critical involvement of community members'.[81]

A third option would be to deploy teams of local engineers to continue monitoring chlorination devices. However, Bangladesh demonstrates a dearth of engineers when compared to neighboring countries.[82] In Bangladesh, it is estimated that there are only 44 engineers per million people, and as of 2019 the country demonstrated an average of 31.16 diarrheal disease-related deaths per 100,000 people. These numbers are striking in comparison to countries like China, which demonstrates 272 engineers per million people and an average of 0.44 diarrheal disease-related deaths per 100,000 people—and South Korea, which demonstrates 1344 engineers per million people and an average of 1.28 diarrheal disease-related deaths per 100,000 people.[83]

Bangladesh's dearth of engineers is due largely to a lack of support and investment at the level of tertiary education. For example, the Bangladesh University of Engineering and Technology (BUET) is the only institution in Bangladesh that offers postgraduate degrees specifically in environmental engineering, and demonstrates a high dropout rate (about 87.4% from the year 2000 to 2006) due to reasons such as limited funding and scholarships, constrained laboratory and research facilities, limited number of courses, and lack of variety in courses in comparison with the global context.[84] It thus becomes apparent how investment in tertiary-level education environmental engineering programs facilitates the maintenance of the necessary infrastructure for providing developing countries like Bangladesh with safe drinking water, thereby decreasing the prevalence of deadly water-borne diseases amongst children and improving general human welfare.

7. Conclusion: looking ahead

Thus, we began by showing that global knowledge inequalities are glaring. These inequalities impact economic development in general, and even more so in regard to the digital revolution in our knowledge economies, which demands a highly skilled workforce. Finally, we sought to show that human development outcomes are also connected to available infrastructure and other aspects of economic development, which in turn are dependent upon research and development, tertiary enrollments, and other forms of TER. In closing, we turn to Unger's suggestion against attempting to provide a fixed blueprint or systematic plan for how countries ought to develop their skilled labor capacities: '[…]we need to tread a path, revising the map along the way'.[85] The most recent Human Development Report (2021–2022) acknowledges the power of human choice—social, economic, and political—in directing innovation toward particular priorities and populations; this is '[…]how technology changes and how innovations advance human development'.[86] It is not acceptable to continue to keep particular communities, groups, or classes disadvantaged in terms of TER, given that we understand the benefits of accessing innovation and the advantages of being at the table that decides norms for this new economic situation.[87]

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Notes

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21. Ibid.
22. Ibid. 1. The patents, in this case, were filed with the USPTO.
23. The pillars are: (1) An economic and institutional regime to provide incentives for the efficient use of existing and new knowledge and the flourishing of entrepreneurship, (2) An educated and skilled population to create, share, and use knowledge well, (3) A dynamic information infrastructure to facilitate the effective communication, dissemination, and processing of information, and (4) An efficient innovation system of firms, research centers, universities, consultants, and other organizations to tap into the growing stock of global knowledge, assimilate and adapt it to local needs, and create new technology. World Bank, Measuring Knowledge in the World's Economies: Knowledge Assessment Methodology and Knowledge Economy Index, November 2008, https://web.worldbank.org/archive/website01030/WEB/IMAGES/KAM_V4.PDF, 1.
24. Chen & Dahlman, 'Knowledge and Development', 4.
25. Ibid. 7. For a more technical primer, see Edmond, Chris. 2008. 'The Aggregate Production Function - New York University'. New York University Stern School of Business. January 9. https://pages.stern.nyu.edu/~cedmond/ge08/notes_production.pdf for an introduction to the production function, and then Dahlman, Carl J., and Derek H. C. Chen. 2004. 'Knowledge and Development: A Cross-Section Approach'. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=616107 to see how Chen & Dahlman develop this production function to derive their understanding of the knowledge economy.
26. Carl Dahlman, 'The Knowledge for Development Program: K4D Newsletter', 2004, https://web.worldbank.org/archive/website01537/WEB/IMAGES/K4DNEW-5.PDF, 1.
27. The Knowledge Economy Index was informed by the Education Index and the Economic and Institution Regime Index. The former was informed by adult literacy rates, and rates of enrollment in primary and secondary educational institutions. The latter was informed by tariff and non-tariff barriers, regulatory quality, and rule of law.
28. The Knowledge Index was informed by the Education Index, the Innovation Index, and the ICT Index. See previous footnote for the education index components. The Innovation Index was informed by royalty payments and receipts, patent count, and number of journal articles published. The ICT Index was informed by the number of telephones, computers, and internet users available.
29. Mohammed Bin Rashid Al Maktoum Knowledge Foundation and United Nations Development Programme, rep., *Global Knowledge Index 2020*; UNDP and MBRF, 2020), https://www.

undp.org/sites/g/files/zskgke326/files/publications/UNDP-MBRKnowFoundation-Global-Kowledge-Index-2020-EN.pdf, x.

30. Ibid. The GKI 2017 seeks to establish an objective tool to measure knowledge in the context of supporting the achievement of sustainable development around the world, including 131 countries in its first edition. The GKI compiles 133 variables from reliable and updated international data sources, and is a composite index structured around seven sectoral indices: Pre-University Education; Technical Vocational Education and Training (TVET); Higher Education; Research, Development and Innovation (RDI); Information and Communication Technology (ICT); Economy; and General Enabling Environment.
31. For good reason—it is widely accepted that increases in these factors lead to exponential development outcomes for an individual, from longer life to better health and the ability to complete their education.
32. See also, John Houghton and Peter Sheehan, ‘A Primer on the Knowledge Economy’ (Melbourne City, VIC: Center for Strategic Economic Studies, Victoria University of Technology, February 2000).
33. Unger, *Knowledge Economy*, 81.
34. Carl Dahlman, Sam Mealy, and Martin Wermelinger, ‘Harnessing the Digital Economy for Developing Countries’, December 22, 2016, 7.
35. Ibid. 7, 26.
36. Ibid. 11.
37. Dahlman, et al., make the distinction between digital economies and internet economies: the internet is a necessary but not sufficient feature of a digital economy.
38. Ibid. 37.
39. Ibid. 37.
40. UNDP, ‘Human Development Report 2021/2022’, Human Development Reports (United Nations Development Program, September 8, 2022), https://hdr.undp.org/system/files/documents/global-report-document/hdr2021-22pdf_1.pdf, 161.
41. David Mhlanga, ‘Artificial Intelligence in the Industry 4.0, and Its Impact on Poverty, Innovation, Infrastructure Development, and the Sustainable Development Goals: Lessons from Emerging Economies?’, Sustainability 13, no. 11 (May 21, 2021): p. 5788, https://doi.org/10.3390/su13115788, 13.
42. UN, ‘The Sustainable Development Goals Report 2022’, United Nations: Department of Economic and Social Affairs, 2022, https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf, 16.
43. Dahlman, et al., also recognize that ‘the digital economy also requires that all participants, including consumers utilizing digital services, possess a minimum level of digital and computer literacy on its users’. (Dahlman, et al., ‘Digital Economy’, 38.) However, this article is primarily concerned with TER and global knowledge inequality, and hence focuses on the infrastructural aspect.
44. Dahlman, et al., ‘Digital Economy’, 38.
45. Ibid. 39.
46. Ibid. 39.
47. Dahlman, ‘Newsletter’, 1.

48. See: Surajit Deb, Gap between GDP and HDI: Are the Rich Country Experiences Different from the Poor?, April 16, 2015, https://old.iariw.org/papers/2015/deb.pdf.
49. Harry Anthony Patrinos, ‘Estimating the Return to Schooling Using the Mincer Equation’, *IZA World of Labor* 278 (July 2016), https://doi.org/10.15185/izawol.278, 1.
50. See Andrew C. Patterson, ‘Is Economic Growth Good for Population Health? A Critical Review’, Canadian Studies in Population 50, no. 1 (March 13, 2023), https://doi.org/10.1007/s42650-023-00072-y. The European Parliament holds that, in a vicious cycle, health inequality itself is correlated with drops in GDP. See WHO, ‘Health Inequities and Their Causes’, World Health Organization (World Health Organization), accessed April 18, 2023, https://www.who.int/news-room/facts-in-pictures/detail/health-inequities-and-their-causes.
51. David Cutler, Angus Deaton, and Adriana Lleras-Muney, ‘The Determinants of Mortality’, *Journal of Economic Perspectives* 20, no. 3 (2006): 97–120, https://doi.org/10.1257/jep.20.3.97, 106–7.
52. Cutler, et al., ‘Mortality’, 116.
53. Ibid. 117.
54. Ibid. 115.
55. In 2015, children from the poorest 20% of households in developing regions were still more than twice as likely to be stunted as those from the wealthiest 20%. See: 1. UN, ‘The Millennium Development Goals Report’, United Nations, July 2015, https://sdgs.un.org/sites/default/files/publications/2036MDG_2015_rev_%28July_1%29.pdf.
56. Sugeng Setyadi, Andi Kustanto, and Anita Widiastuti, ‘Life Expectancy in Indonesia: The Role of Health Infrastructure, Political, and Socioeconomic Status’, *Iranian Economic Review* 23, no. 2 (December 18, 2021), https://doi.org/10.22059/ier.2021.85012.
57. Endri Kristanto, Akhmad Daerobi, and Bhimo Rizky Samudro, ‘Indonesian Life Expectancy: Role of Health Infrastructure and Socio-Economic Status’, *Signifikan: Jurnal Ilmu Ekonomi* 8, no. 2 (2019): pp. 159–178, https://doi.org/10.15408/sjie.v8i2.9579.
58. WHO, ‘Health Inequities and Their Causes’, World Health Organization (World Health Organization), accessed April 18, 2023, https://www.who.int/news-room/facts-in-pictures/detail/health-inequities-and-their-causes.
59. Letícia Xander Russo et al., ‘Primary Care Physicians and Infant Mortality: Evidence from Brazil’, *PLoS One* 14, no. 5 (May 31, 2019), https://doi.org/10.1371/journal.pone.0217614.
60. WHO, ‘Tackling Neglected Tropical Diseases with Water Sanitation and Hygiene’, World Health Organization (World Health Organization), accessed April 18, 2023, https://www.who.int/news-room/facts-in-pictures/detail/tackling-neglected-tropical-diseases-with-water-sanitation-and-hygiene.
61. Jarmo Peltola and Sakari Saaritsa, ‘Later, Smaller, Better? Water Infrastructure and Infant Mortality in Finnish Cities and Towns, 1870–1938’, The History of the Family 24, no. 2 (April 22, 2019): pp. 277–306, https://doi.org/10.1080/1081602x.2019.1598462.
62. UN, ‘Addressing Energy’s Interlinkages with Other SDGs’, United Nations: Department of Economic and Social Affairs, 2022, https://sdgs.un.org/sites/default/files/2022-06/2022-UN_SDG7_Brief-053122.pdf, 9.
63. Heru Kusharjanto and Donghun Kim, ‘Infrastructure and Human Development: The Case of Java, Indonesia’, Journal of the Asia Pacific Economy 16, no. 1 (January 13, 2011): pp. 111–124, https://doi.org/10.1080/13547860.2011.539407. The authors point out further that even upon excluding

the four largest urban areas, the relationship between infrastructure and HDI holds (see note 4 of the article).
64. Jeet Bahadur Sapkota, 'Access to Infrastructure and Human Well-Being: Evidence from Rural Nepal', *Development in Practice* 28, no. 2 (February 20, 2018): pp. 182–194, https://doi.org/10.1080/09614524.2018.1424802.
65. UN, 'SDGs Report 2022', 13.
66. UN, 'SDGs Report 2022', 19.
67. See: Roberta Malee Bassett and Danica Ramljak, 'Montenegro: How a Higher Education and Innovation Project Is Helping COVID-19 (Coronavirus) Response', web log, *World Bank Blogs* (blog) (The World Bank, 2020), https://blogs.worldbank.org/education/montenegro-how-higher-education-and-innovation-project-helping-covid-19-coronavirus.
68. Neville Calleja et al., 'Managing COVID-19 in Four Small Countries: Initial Response to the Pandemic in San Marino, Montenegro, Malta and Cyprus', *Health Policy* 126, no. 4 (2022): 281–86, https://doi.org/10.1016/j.healthpol.2022.01.008, 284.
69. Ibid. 284.
70. Real-time reverse transcription-polymerase chain reaction machine: a highly specialized technological method for virus detection.
71. Bassett & Ramljak, 'Montenegro'.
72. World Bank, 'Bangladesh: Can Automated Chlorination at Shared Water Taps Reduce Disease in Urban Slums?', The World Bank, 2020, https://documents1.worldbank.org/curated/en/882781602861047266/pdf/World-COVID-19-Strategic-Preparedness-and-Response-Program-SPRP-using-the-Multiphase-Programmatic-Approach-MPA-Project-Additional-Financing.pdf, 1.
73. Ataur Rahman et al., 'A Review and Analysis of Water Research, Development, and Management in Bangladesh', *Water* 14, no. 12 (2022): 1–28, https://doi.org/10.3390/w14121834, 2.
74. World Bank, 'Bangladesh', 1.
75. Ibid. 3.
76. Amy J Pickering et al., 'Effect of In-Line Drinking Water Chlorination at the Point of Collection on Child Diarrhoea in Urban Bangladesh: A Double-Blind, Cluster-Randomised Controlled Trial', *The Lancet* 7, no. 9 (2019): e1247–56, https://doi.org/10.1016/s2214-109x(19)30315-8, e1255.
77. World Bank, 'Bangladesh', 4.
78. Ibid. 2.
79. In an online magazine article for Stanford Engineering, Ruthann Richter writes, "'The community groups could hire residents for a small fee to periodically refill the chlorine reservoirs and make sure the devices are working properly. [...] Another alternative could involve local entrepreneurs to maintain the devices, as there are many in Dhaka eager for a steady source of income'. See: Ruthann Richter, 'Stanford Engineers Debug Dhaka's Water', Stanford University School of Engineering, 2013, https://engineering.stanford.edu/magazine/article/stanford-engineers-debug-dhaka-s-water.
80. Pickering, et al., 'Child Diarrhoea', e1248.
81. Md. Sazzadul Haque and Shafkat Sharif, 'The Need for an Effective Environmental Engineering Education to Meet the Growing Environmental Pollution in Bangladesh', *Cleaner Engineering and Technology* 4, no. 100114 (2021): 1–19, 13.

82. Skilled engineers are vital to a variety of development solutions. For instance, the treatment and delivery of potable water relies upon civil engineers at multiple points—not only to operate water and sewage treatment plants, but also to operate the electrical grid, which powers the treatment plants; as well as the expertise related to construction, to lay pipes for the water delivery system.
83. Numbers sourced from: Haque & Sharif, 'Environmental Pollution', 8 and Our World in Data, 'Death Rate from Diarrheal Diseases, 1990 to 2019', Our World in Data, 2021, https://ourworldindata.org/grapher/diarrheal-disease-death-rates?tab=chart.
84. Haque & Sharif, 'Environmental Pollution'.
85. Unger, *Knowledge Economy*, 171–2.
86. UNDP, 'Human Development Report 2021/2022', Human Development Reports (United Nations Development Program, September 8, 2022), https://hdr.undp.org/system/files/documents/global-report-document/hdr2021-22pdf_1.pdf, 160.
87. Reducing inequality between and among countries is SDG #10.

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