CHAPTER

# 14

# Education, knowledge capital, and economic growth

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Education has long been viewed as an important determinant of economic well-being. While theoretical discussions strongly emphasize the role of human capital in growth, the bulk of empirical analysis is more mixed. In large part, this mixed evidence appears to reflect measurement issues. Once corrected to allow for both quality of schools and the varied sources of skills, the skills-growth relationship becomes clear and strong.

The theoretical growth literature emphasizes at least three mechanisms through which education may affect economic growth. First, education can increase the human capital inherent in the labor force, which increases labor productivity and thus transitional growth toward a higher equilibrium level of output (as in augmented neoclassical growth theories, cf. Mankiw, Romer, & Weil, 1992). Second, education can increase the innovative capacity of the economy, and the development of new technologies, products and processes promotes growth (as in theories of endogenous growth, cf., e.g., Lucas, 1988; Romer, 1990; Aghion & Howitt, 1998). Third, education can facilitate the diffusion and transmission of knowledge needed to understand and process new information and to implement successfully new technologies devised by others, which again promotes economic growth (cf., e.g., Nelson & Phelps, 1966; Benhabib & Spiegel, 1994).

Despite these overall theoretical predictions, empirical testing has been less conclusive and open to more questions. Most people would acknowledge that a year of schooling does not produce the same cognitive skills everywhere. They would also agree that families and peers contribute to education. Health and nutrition further impact cognitive skills. Yet until recently, research on the economic impact of education—largely due to expedience—has almost uniformly ignored these aspects and has focused almost exclusively on school attainment. Recent research shows that ignoring differences in the quality of education significantly distorts the picture of how educational and economic outcomes are related.

This discussion focuses on how measures of knowledge capital—the aggregate cognitive skills of a country—reconcile the theoretical

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importance and the empirical evidence on the role of human capital in growth. The discussion further underscores the fundamental importance of skills for economic development.

## Early studies of schooling quantity and economic growth

The majority of the empirical macroeconomic literature on economic returns to education employs measures of the quantity of schooling. The most common measure is years of schooling, averaged across the working-age population. (Woessmann (2003b) surveys issues of measuring and specifying human capital from early growth accounting to early cross-country growth regressions.) The standard method of estimating the effect of education on economic growth is to estimate cross-country growth regressions where average annual growth in gross domestic product (GDP) per capita over several decades is expressed as a function of measures of schooling and a set of other variables deemed important for economic growth.

Following the classical contributions by Barro (1991, 1997) and Mankiw et al. (1992), a vast early literature of cross-country growth regressions tended to find a significant positive association between quantitative measures of schooling and economic growth. Extensive reviews of the literature are found in Topel (1999), Temple (2001), Krueger & Lindahl (2001), and Sianesi & Van Reenen (2003). To provide an idea of the robustness of the basic association, primary schooling turns out to be the most robust influence factor (after an East Asian dummy) on growth in GDP per capita in 1960–96 in the extensive robustness analysis of 67 explanatory variables in growth regressions on a sample of 88 countries by Sala-i-Martin, Doppelhofer, & Miller (2004).

Fig. 14.1 provides a basic representation of the association between years of schooling and economic growth from 1960 to 2000. This basic relationship suggests that each year of schooling is associated with long-run growth that is 0.58% points higher, although much of the differences in growth across countries is unaccounted for.

Yet, questions developed regarding the interpretation of such relationships, and these questions persist. A substantial controversy addresses whether it is the level of years of schooling (as would be predicted by several models of endogenous growth) or the change in years of schooling (as would be predicted by basic neoclassical models) that is the more important driver of economic growth (e.g., Krueger & Lindahl, 2001)). It seems beyond the scope of current data to draw strong conclusions about the relative importance of different mechanisms for schooling quantity to affect economic growth. Even so, several recent studies suggest that education is important both as an investment in human capital and in facilitating research and development and the diffusion of technologies, with initial phases of education more important for imitation and higher education for innovation (Vandenbussche, Aghion, & Meghir, 2006).

Three more skeptical studies introduce doubts about the interpretation of the estimates. Bils & Klenow (2000) raise the issue of causality, suggesting that reverse causation running from higher economic growth to additional education may be at least as important as the causal effect of education on growth in the cross-country association. Pritchett (2001, 2006) raises questions about the plausibility of simple growth models with years of schooling and stresses that it is important for economic growth to get other things right as well, in particular the institutional framework of the economy. Third, Levine & Renelt (1992) and Levine & Zervos (1993) raise questions about the instability of empirical estimates and the sensitivity to model specification. Each issue will be discussed further below.

But most importantly, using average years of schooling as an education measure implicitly assumes that a year of schooling delivers the same

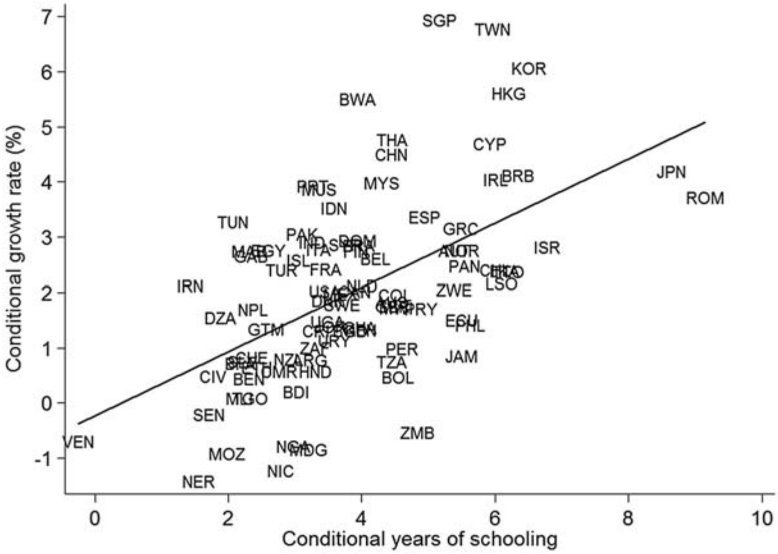


FIG. 14.1 Years of schooling and economic growth rates without considering knowledge capital. Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on average years of schooling in 1960 and initial level of real GDP per capita in 1960 (mean of unconditional variables added to each axis). *Source:* *Hanushek & Woessmann (2015a).*

increase in knowledge and skills regardless of the education system. This measure also assumes that formal schooling is the primary source of education and that variations in the quality of nonschool factors affecting learning have a negligible effect on education outcomes. This neglect of cross-country differences in the quality of education now appears to be the major drawback of application of school attainment as a quantitative measure of national skills.

## Early evidence on the quality of education and economic growth

Quite clearly the average student in Ghana or Peru does not gain the same amount of knowledge in any year of schooling as the average student in Finland or Korea, but using measures of years of schooling in cross-country growth analysis assumes that they are equivalent. In addition, using years of schooling implicitly assumes that all skills and human capital come from formal schooling, even though extensive evidence on knowledge development and cognitive skills indicates that a variety of factors outside of school—family, peers, and others—have a direct and powerful influence (Hanushek, 2002; Woessmann, 2003a). Ignoring these nonschool factors introduces the possibility of serious bias in the estimation of growth models based on school attainment.

Since the mid-1960s, international agencies such as the International Association for the Evaluation of Educational Achievement (IEA) and the Organization for Economic Co-operation and Development (OECD) have conducted many international tests—such as TIMSS, PISA, and their predecessors—of student performance in cognitive skills such as mathematics and science. Incorporating these measures of cognitive skills into growth analysis dramatically alters the assessment of the role of education in economic development.

Using the data from the international student achievement tests through 1991 to build a measure of educational quality, Hanushek & Kimko (2000) find a statistically and economically significant positive effect of the quality of education on economic growth in 1960–90 that is far larger than the association between the quantity of schooling and growth. Ignoring quality differences very significantly misses the true importance of education for economic growth. Their estimates suggest that one country-level standard deviation (equivalent to 47 test-score points in PISA 2000 mathematics, the same scale used in Fig. 14.2 below) higher test performance would yield about one percentage point higher annual growth.

That estimate stems from a statistical model that relates annual growth rates of real GDP per capita to the measure of educational quality, years of schooling, the initial level of income, and several other control variables (including, in different specifications, the population growth rates, political measures, openness of the economies, and the like). Adding educational quality to a base specification including only initial income and educational quantity boosts the variance in GDP per capita among the 31 countries in Hanushek and Kimko's sample that can be explained by the model from 33% to 73%. The effect of years of schooling is greatly reduced by including quality, leaving it mostly insignificant. At the same time, adding the other factors leaves the effects of cognitive skills basically unchanged.

Several studies have since found very similar results, including Barro (2001), Woessmann (2003b), Bosworth and Collins (2003), and Coulombe and Tremblay (2006); see Hanushek & Woessmann (2008) for a review. In sum, the evidence suggests that the quality of education, measured by the knowledge that students gain as depicted in tests of cognitive skills, is substantially more important for economic growth than the mere quantity of schooling.

## Recent evidence on the importance of cognitive skills for economic growth

The most recent evidence, summarized in Hanushek & Woessmann (2015a), adds international student achievement tests not previously available, refines the aggregation of the various international tests, and uses the recent data on economic growth to analyze an even longer period (1960–2000).

Hanushek & Woessmann (2012a), relying on the 36 international tests from 12 testing occasions comparable between 1965 and 2003, develop a consistent metric of the aggregate cognitive skills, or knowledge capital, of nations. They adjust both the level of test performance and its variation through two data transformations. First, each of the separate international tests is benchmarked to a comparable level by calibrating the US international performance over time to the external standard of the available US longitudinal test (the National Assessment of Educational Progress, NAEP). Second, the dispersion of the tests is standardized by holding the score variance constant within a group of 13 OECD countries with relatively stable secondary school attendance rates over time. They are able to extend the sample of countries with available test-score and growth information to 50 countries. These data are also used to analyze effects of the distribution of educational quality at the bottom and at the top on economic growth, as well as interactions between educational quality and the institutional infrastructure of an economy.

The measure of knowledge capital is a simple average of the mathematics and science scores over international tests, interpreted as a proxy for the average educational performance of the whole labor force. This measure encompasses overall cognitive skills, not just those developed in schools. Thus, whether skills are developed at home, in schools, or elsewhere, they are included in the growth analyses.

After controlling for the initial level of GDP per capita and for years of schooling (Hanushek & Woessmann, 2015a), the knowledge capital measure features a highly statistically significant effect on the growth of real GDP per capita in 1960–2000 (Fig. 14.2). According to this simple specification, test scores that are larger by one standard deviation (measured at the student

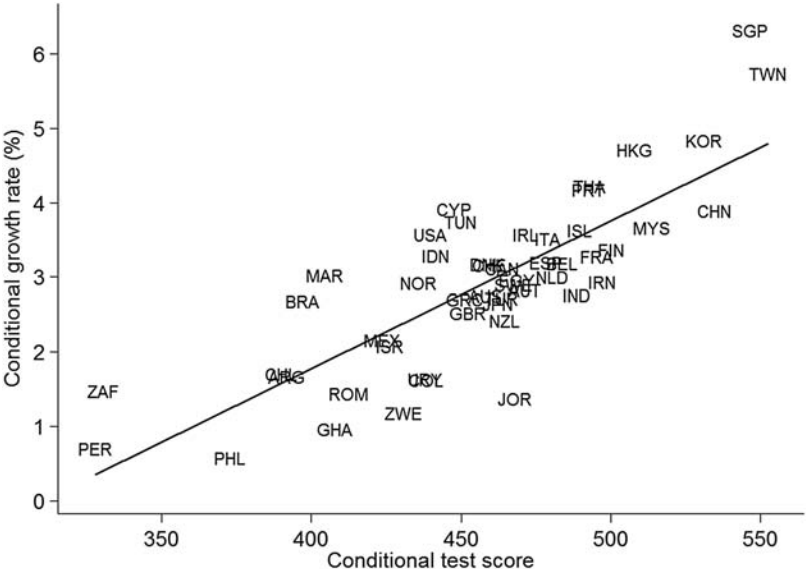


**FIG. 14.2** Knowledge capital and economic growth rates across countries. Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on average test scores on international student achievement tests, average years of schooling in 1960, and initial level of real GDP per capita in 1960 (mean of unconditional variables added to each axis). *Source: Hanushek and Woessmann (2015a).*

level across all OECD countries in PISA) are associated with an average annual growth rate in GDP per capita that is two percentage points higher over the whole 40-year period.

Adding educational quality to a model that just includes initial income and years of schooling increases the share of variation in economic growth explained from 25% to 73%. As reported above, the quantity of schooling is statistically significantly related to economic growth in a specification that neglects educational quality, but the association between years of schooling and growth turns insignificant and is reduced to close to zero once the quality of education is included in the model (Fig. 14.3). Additionally, considering the variation just within each of five world regions, educational quality is significantly related to economic growth, indicating that it does not simply reflect economic differences across regions.

Recent literature on the determinants of economic growth emphasizes the importance of the institutional framework of the economy (e.g., Acemoglu, Johnson, & Robinson, 2005, 2012). The most common and powerful measures of the institutional framework used in empirical work are the openness of the economy to international trade and the security of property rights. These two institutional variables are jointly highly significant when added to the basic growth model. But the positive effect of educational quality on economic growth is very robust to the inclusion of these controls, although its magnitude is slightly reduced by about one-third. Further, Glaeser, Porta, Lopez-de-Silanes, and Shleifer (2004) question whether the institutions themselves are an outcome of more human capital.

Other possible determinants of economic growth often discussed in the literature are fertility and geography. But when the total fertility rate and common geographical proxies, such as latitude or the fraction of the land area located within the geographic tropics, are added to the model, neither is statistically significantly associated with economic growth.

The results are remarkably similar when comparing the sample of OECD countries to the sample of non-OECD countries, with the point estimate of the effect of educational quality

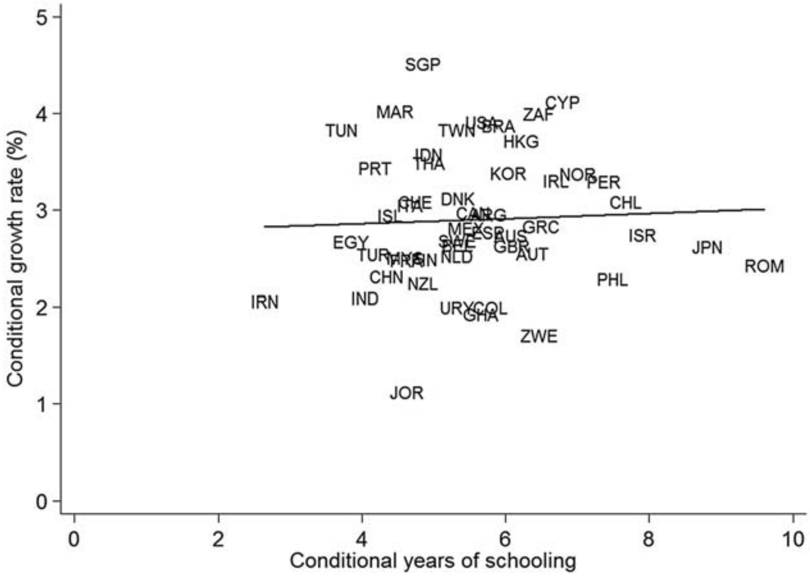


FIG. 14.3 Years of schooling and economic growth rates after considering knowledge capital. Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on average years of schooling in 1960, average test scores on international student achievement tests, and initial level of real GDP per capita in 1960 (mean of unconditional variables added to each axis). *Source:* *Hanushek and Woessmann (2015a).*

slightly larger in non-OECD countries. When the sample is separated based on whether a country was below or above the median of GDP per capita in 1960, the effect of educational quality is statistically significantly larger in low-income countries than in high-income countries (cf. Hanushek & Woessmann, 2015a). Specific analyses focusing on Latin America (Hanushek & Woessmann, 2012b) and on East Asia (Hanushek & Woessmann, 2016) confirm and extend the basic results. More recently, the importance of knowledge capital for long-run economic growth has also been shown in within-country analyses across US states (Hanushek, Ruhose, & Woessmann, 2017a, 2017b).

## Causality in brief

The fundamental question is: should this tight relationship between cognitive skills and economic growth be interpreted as a causal one that can support direct policy actions? In other words, if achievement were raised, would growth rates really be expected to go up by a commensurate amount?

The early studies that found positive effects of years of schooling on economic growth may have, indeed, been suffering from simple reverse causality, that is, improved growth was leading to more schooling rather than the reverse (Bils & Klenow, 2000). If a country gets richer, it tends to buy more of many things, including more years of schooling for its population.

There is less reason to think that higher student achievement is caused by economic growth. For one thing, scholars have found little impact of additional education spending on achievement outcomes, so it is unlikely that the relationship comes from growth-induced resources lifting student achievement (Hanushek & Woessmann, 2011a). Still, it remains difficult to develop conclusive tests of causality with the limited sample of countries included in this analysis.

Hanushek & Woessmann (2012a) present evidence on a series of tests of causality that offers some assurance that the issues most frequently cited as being potentially problematic are not affecting the results. First, the estimated relationship is little affected by including other possible determinants of economic growth. These specification tests rule out many basic problems attributable to omitted causal factors that have been noted in prior growth work.

Second, the most obvious concerns about reverse-causality issues arise because the analysis relates growth rates over the period 1960 to 2000 to test scores for roughly the same period. To address this directly, the timing of the analysis is separated by estimating the effect of scores on tests conducted only until 1984 on economic growth in the period since 1985 (and until 2009). In this analysis, available for a sample of 25 countries only, test scores strictly pre-date the growth period, making it clear that increased growth could not be causing the higher test scores of the prior period. This estimation shows a positive effect of early test scores on subsequent growth rates that is almost twice as large as that displayed above. Indeed, this fact itself may be significant, because it is consistent with the possibility that skills have become even more important for the economy in recent periods.

Third, even if reverse causality were not an issue, it does ensure that the important international differences in test scores reflect school policies and not, say, health and nutrition differences in the population or simply because of cultural differences regarding learning and testing. Nevertheless, attention can be focused just on variations in achievement that arise directly from institutional characteristics of each country's school system (exit examinations, autonomy, relative teacher salaries, and private schooling). This instrumental variable estimation of the growth relationship yields essentially the same results as previously presented, lending support both to the causal interpretation of the effect of cognitive skills and to the conclusion that schooling policies can have direct economic returns.

Fourth, a major concern is that countries with good economies also have good school systems, implying that those that grow faster because of the basic economic factors also have high achievement. In this case, achievement is simply a reflection of other important aspects of the economy and not the driving force in growth. One simple approach is to consider the implications of differences in measured skills within a single economy, thus eliminating institutional or cultural factors that may make the economies of different countries grow faster. This can readily be done for immigrants to the United States who have been educated in their home countries and who can be compared to those immigrants educated just in the United States. Since the two groups are within the single labor market of the United States, any differences in labor-market returns associated with cognitive skills cannot arise because of differences in the economy or culture of their home country. Looking at labor-market returns, immigrants from countries with higher cognitive skills tend to have higher incomes, but only if the immigrant was in fact educated in the home country. Immigrants from the same home country schooled in the United States see no economic return to home-country test scores, thus pinpointing the value of better schools. This comparative analysis rules out the possibility that test scores simply reflect cultural factors or economic institutions of the home country.

Finally, for those countries that have participated in testing at different points over the past half century, it can be observed whether or not students are getting better or worse over time. Building on this, perhaps the toughest test of causality is relating *changes* in test scores over time to *changes* in growth rates. This approach implicitly eliminates country-specific economic and cultural factors because it looks at what happens over time within each country. While considering this relationship is only possible for 12 OECD countries (because of historical testing patterns), the gains in test scores over time are very closely related to the gains in growth rates over time.

Each approach to determining causation is subject to its own uncertainty (Hanushek &

Woessmann, 2012a). Nonetheless, the combined evidence consistently points to the conclusion that differences in cognitive skills lead to significant differences in economic growth.

## The interaction of educational quality with economic institutions

Economic institutions appear to interact with the effect of educational quality on economic growth. The institutional framework of a country affects the relative profitability of piracy and productive activity. If the available knowledge and skills are used in the former activity rather than the latter, the effect on economic growth may be very different, perhaps even turning negative (North, 1990).

Past work supports the possible direct effects of a country's institutions. The allocation of talent between rent-seeking and entrepreneurship matters for growth: countries with more engineering students grow faster and countries with more law students grow more slowly (Murphy, Shleifer, & Vishny, 1991). Education may not have much impact in less developed countries that lack other facilitating factors such as functioning institutions for markets and legal systems (Easterly, 2001). And due to deficiencies in the institutional environment, cognitive skills might be applied to socially unproductive activities in many developing countries (Pritchett, 2001).

Adding the interaction of educational quality and one institutional measure—openness to international trade—to the growth specification indicates not only that both have significant individual effects on economic growth but also that there is a significant positive interaction. The effect of educational quality on economic growth is indeed significantly higher in countries that have been fully open to international trade than in countries that have been fully closed. The effect of educational quality on economic growth is significantly positive, albeit relatively low, at 0.9 per s.d. in closed economies but increases to 2.5 per s.d. in open economies. When using protection against expropriation rather than openness to trade as the measure of institutional quality, there is similarly a positive interaction term with educational quality, although it lacks statistical significance.

In sum, both the quality of the institutional environment and the quality of education seem important for economic development. Furthermore, the effect of knowledge capital on growth seems significantly larger in countries with a productive institutional framework, so that good institutional quality and good educational quality can reinforce each other. Thus, the macroeconomic effect of education depends on other complementary growth-enhancing policies and institutions. But cognitive skills have a significant positive growth effect even in countries with a poor institutional environment.

## Simulating the impact of educational reform on economic growth

Development strategies invariably include education and human capital improvement as important components. These have tended until recently to focus on quantitative goals, such as achieving certain levels of educational enrollment or attainment. For example, the two Millennium Development Goals related to education that the United Nations adopted in 2000 – universal primary education and gender parity by 2015 – are solely phrased in terms of educational quantity (United Nations, 2009). Similarly, while UNESCO's Education for All initiative mentioned quality, its explicit goals mostly focused on school quantity (UNESCO, 2008).

Amidst educational progress, development strategies built just on schooling have disappointed because expansion of school attainment has not guaranteed improved economic conditions (Easterly, 2001). Thus, when the United

Nations in 2015 revisited its development goals in the Sustainable Development Goals or SDG's, the education component included explicit mention of quality, although stopping short of quantified quality targets. This is perhaps a natural acknowledgment that lower-income countries still have generally incomplete enrollment in lower secondary schools, but it still raises the possibility of overemphasis of attainment at the cost of lower quality. In general, the SDG's highlight the long standing tension between goals framed in terms of school completion (which is readily and routinely measured) and quality (which less frequently measured).

To show the value of improved quality of schooling, Hanushek & Woessmann (2015b) project the economic impacts of country changes in access and quality of schooling. Three improvements in student performance are considered. In the first, each country moves to full access to lower secondary schooling at the current quality level. In the second, all students currently in school with insufficient skills are brought up to at least to a basic skill level. In the third, both moves simultaneously occur.

Their projections rely on a simple description of how skills enter the labor market and have an impact on the economy. Improvement occurs linearly from today's schooling situation in each country to reaching the goal in 15 years. Assuming that a worker remains in the labor force for 40 years implies that the labor force is progressively made up of increasingly more skilled workers for 55 years (15 years of reform and 40 years of replacement of retiring, less-skilled workers), after which all workers are at the new improved quality level. The difference in GDP is then estimated with an improved workforce versus the existing workforce skills over 80 years, roughly the life expectancy of somebody in a developed country born today. Future gains in GDP are discounted from the present with a 3% discount rate. The resulting present value of additions to GDP is thus directly comparable to the current levels of GDP. (See Hanushek & Woessmann (2010, 2011b, 2015b) for details of the projection methodology.)

Hanushek & Woessmann (2015b) define basic skills by a simple PISA test standard, where the OECD defines fully achieving Level 1 on the PISA test as representing the skills necessary in order to participate productively in modern economies.

Fig. 14.4 displays their projection results for four groupings of countries (according to World Bank categories): lower middle income, upper middle income, high income non-OECD, and high income OECD. Lower middle income countries include such countries as Ghana, Honduras, Indonesia, and Morocco. Examples of upper middle income are Argentina, Bulgaria, South Africa, and Turkey. The high income non-OECD includes Hong Kong, Lithuania, and several Arab oil-producing countries. Again, however, the 76 countries included in the overall projections are restricted to countries that have recently participated in PISA or TIMSS testing so that a measure of quality is available.

The first grouping of bars on the graph in Fig. 14.4 show the gains from improving quality for existing access levels to schools. The lower middle income countries on average would see gains in the average level of GDP over the next 80 years of 13%, but even high income OECD countries would on average gain three percent in GDP from bringing all students up to basic skills (PISA Level 1).

The second set of columns shows the economic impact of ensuring access of all children through lower secondary but maintaining existing quality levels. While this has essentially no impact on high income OECD countries where access is almost complete now, it has noticeable impact for the other sets of countries. For lower middle income countries, which currently average about 80% completion of lower secondary schooling, the gains would on average lift future GDP levels by 4.4%.

These two sets of projections show the tension that has existed in setting international goals for

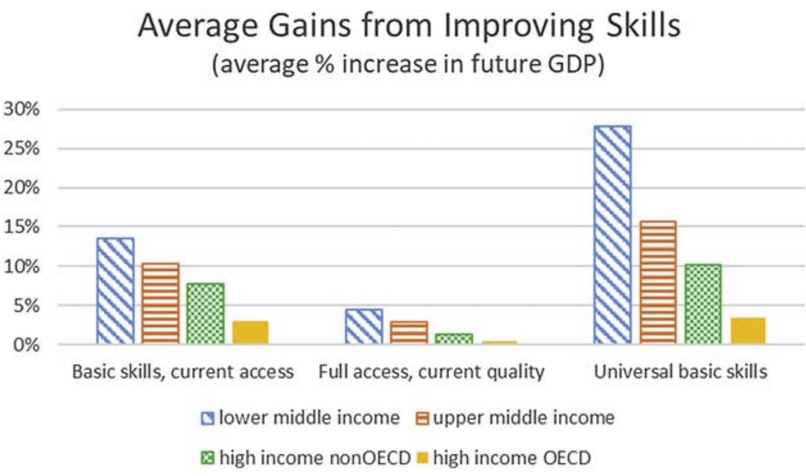


FIG. 14.4 Projections of expanded access and improved quality of schools by level of development. *Source: Own depiction based on Hanushek and Woessmann (2015b).*

schooling. Full access clearly has value, but the value is significantly less than seen through quality improvements.

The final set of columns in Fig. 14.4 shows the result of achieving simultaneous improvements in access and quality. Lower middle income countries gain on average 28% higher GDP, and upper middle income countries gain 16% in the level of future GDP. This broader quality dimension is also relevant to upper income countries, since they today have numbers of students who do not get to basic skill levels. For example, in the US 23% of 15-year-olds do not get to Level 1 in mathematics; getting them to Level 1 implies a future GDP that would be 3.3% higher on average.

The simulations in Hanushek & Woessmann (2015b) show that the previous estimates of the effects of knowledge capital on growth have large impacts on national economies. They also suggest that directly focusing on school quality is important for economic development.

## Summary

The accumulated evidence from analyses of economic outcomes is that the quality of education—measured on an outcome basis of cognitive skills—has powerful economic effects. Economic growth is strongly affected by the knowledge capital of workers.

This message is important in developed and developing countries alike. In the latter, much of the discussion of development policy today simplifies and distorts this message. It recognizes that education matters, but focuses most attention on ensuring that everybody is in school—regardless of the learning that goes on. Because of the reported findings—that knowledge rather than just time in school is what counts for economic growth—policies must pay more attention to the quality of schools.

## References

Acemoglu, D., Johnson, S., & Robinson, J. A. (2005). Institutions as a fundamental cause of long-run growth. In P. Aghion, & S. N. Durlauf (Eds.), *Handbook of economic growth* (pp. 385–472). Amsterdam: North Holland.

Acemoglu, D., Johnson, S., & Robinson, J. A. (2012). The colonial origins of comparative development: An empirical investigation: Reply. *The American Economic Review, 102*(6), 3077–3110.

Aghion, P., & Howitt, P. (1998). *Endogenous growth theory*. Cambridge, MA: MIT Press.

Barro, R. J. (1991). Economic growth in a cross section of countries. *Quarterly Journal of Economics, 106*(2), 407–443.

Barro, R. J. (1997). *Determinants of economic growth: A cross-country empirical study*. Cambridge, MA: MIT Press.

Barro, R. J. (2001). Human capital and growth. *The American Economic Review, 91*(2), 12–17.

Benhabib, J., & Spiegel, M. M. (1994). The role of human capital in economic development: Evidence from aggregate cross-country data. *Journal of Monetary Economics, 34*(2), 143–174.

Bils, M., & Klenow, P. J. (2000). Does schooling cause growth? *The American Economic Review, 90*(5), 1160–1183.

Bosworth, B. P., & Collins, S. M. (2003). The empirics of growth: An update. *Brookings Papers on Economic Activity, 2*, 113–206.

Coulombe, S., & Tremblay, J.-F. (2006). Literacy and growth. *Topics in Macroeconomics, 6*(2). Article 4.

Easterly, W. (2001). *The elusive quest for growth: An economist's adventures and misadventures in the tropics*. Cambridge, MA: The MIT Press.

Glaeser, E. L., Porta, R. L., Lopez-de-Silanes, F., & Shleifer, A. (2004). Do institutions cause growth? *Journal of Economic Growth, 9*(3), 271–303.

Hanushek, E. A. (2002). Publicly provided education. In A. J. Auerbach, & M. Feldstein (Eds.), *Handbook of public economics* (Vol. 4, pp. 2045–2141). Amsterdam: North Holland.

Hanushek, E. A., & Kimko, D. D. (2000). Schooling, labor force quality, and the growth of nations. *The American Economic Review, 90*(5), 1184–1208.

Hanushek, E. A., Ruhose, J., & Woessmann, L. (2017a). Economic gains from educational reform by US States. *Journal of Human Capital, 11*(4), 447–486.

Hanushek, E. A., Ruhose, J., & Woessmann, L. (2017b). Knowledge capital and aggregate income differences: Development accounting for U.S. states. *American Economic Journal: Macroeconomics, 9*(4), 184–224.

Hanushek, E. A., & Woessmann, L. (2008). The role of cognitive skills in economic development. *Journal of Economic Literature, 46*(3), 607–668.

Hanushek, E. A., & Woessmann, L. (2010). *The high cost of low educational performance: The long-run economic impact of improving PISA outcomes*. Paris: Organisation for Economic Cooperation and Development.

Hanushek, E. A., & Woessmann, L. (2011a). The economics of international differences in educational achievement. In E. A. Hanushek, S. Machin, & L. Woessmann (Eds.), *Handbook of the economics of education* (Vol. 3, pp. 89–200). Amsterdam: North Holland.

Hanushek, E. A., & Woessmann, L. (2011b). How much do educational outcomes matter in OECD countries? *Economic Policy, 26*(67), 427–491.

Hanushek, E. A., & Woessmann, L. (2012a). Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. *Journal of Economic Growth, 17*(4), 267–321.

Hanushek, E. A., & Woessmann, L. (2012b). Schooling, educational achievement, and the Latin American growth puzzle. *Journal of Development Economics, 99*(2), 497–512.

Hanushek, E. A., & Woessmann, L. (2015a). *The knowledge capital of nations: Education and the economics of growth*. Cambridge, MA: MIT Press.

Hanushek, E. A., & Woessmann, L. (2015b). *Universal basic skills: What countries stand to gain*. Paris: Organisation for Economic Co-operation and Development.

Hanushek, E. A., & Woessmann, L. (2016). Knowledge capital, growth, and the East Asian miracle. *Science, 351*(6271), 344–345.

Krueger, A. B., & Lindahl, M. (2001). Education for growth: Why and for whom? *Journal of Economic Literature, 39*(4), 1101–1136.

Levine, R., & Renelt, D. (1992). A sensitivity analysis of cross-country growth regressions. *The American Economic Review, 82*(4), 942–963.

Levine, R., & Zervos, S. J. (1993). What we have learned about policy and growth from cross-country regressions. *The American Economic Review, 83*(2), 426–430.

Lucas, R. E., Jr. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(1), 3–42.

Mankiw, N. G., Romer, D., & Weil, D. (1992). A contribution to the empirics of economic growth. *Quarterly Journal of Economics, 107*(2), 407–437.

Murphy, K. M., Shleifer, A., & Vishny, R. W. (1991). The allocation of talent: Implications for growth. *Quarterly Journal of Economics, 106*(2), 503–530.

Nelson, R. R., & Phelps, E. (1966). Investment in humans, technology diffusion and economic growth. *The American Economic Review, 56*(2), 69–75.

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge: Cambridge University Press.

Pritchett, L. (2001). Where has all the education gone? *The World Bank Economic Review, 15*(3), 367–391.

Pritchett, L. (2006). Does learning to add up add up? The returns to schooling in aggregate data. In E. A. Hanushek, & F. Welch (Eds.), *Handbook of the economics of education* (pp. 635–695). Amsterdam: North Holland.

Romer, P. (1990). Endogenous technological change. *Journal of Political Economy, 99*(5), S71–S102. pt. II.

Sala-i-Martin, X., Doppelhofer, G., & Miller, R. I. (2004). Determinants of long-term growth: A Bayesian averaging of classical estimates (BACE) approach. *The American Economic Review, 94*(4), 813–835.

Sianesi, B., & Van Reenen, J. (2003). The returns to education: Macroeconomics. *Journal of Economic Surveys, 17*(2), 157–200.

Temple, J. (2001). Growth effects of education and social capital in the OECD countries. *OECD Economic Studies, 33*, 57–101.

Topel, R. (1999). Labor markets and economic growth. In O. Ashenfelter, & D. Card (Eds.), *Handbook of labor economics* (pp. 2943–2984). Amsterdam: Elsevier.

UNESCO. (2008). Overcoming inequality: Why governance matters. *EFA Global monitoring report 2009*. Paris: UNESCO.

United Nations. (2009). *The millennium development goals report 2009*. New York: United Nations.

Vandenbussche, J., Aghion, P., & Meghir, C. (2006). Growth, distance to frontier and composition of human capital. *Journal of Economic Growth, 11*(2), 97−127. June.

Woessmann, L. (2003a). Schooling resources, educational institutions, and student performance: The international evidence. *Oxford Bulletin of Economics & Statistics, 65*(2), 117−170.

Woessmann, L. (2003b). Specifying human capital. *Journal of Economic Surveys, 17*(3), 239−270.