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Innovations in education for better skills and higher employability

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Executive Summary (English)

This report discusses aspects of the relationship between innovations in education and the innovative capacity of the economy. The role of education is to develop critical skills for improved conditions for innovations in the economy, which requires innovations within the educational sector itself. The report consists of four parts. The first part is on innovations in teaching and learning, with a special focus on new technologies that expand the educational toolbox. The second part is on teachers. The success of new teaching methods depends on the ability of the teachers to invent and apply innovative teaching methods, and how incentives can be designed to foster successful implementations of such methods. The third part is on skills. The role of education is to deliver skilled and innovative students to the workforce, and when the demand for different types of skills changes, the educational sector should respond correspondingly. The last part is on governance for innovation and improvements in education.

We conclude that increased use of technology in teaching is not a panacea for improved student achievement and that intensified causal research on various innovative teaching methods and experiments is needed. Since the individual teacher is essential when it comes to innovations in teaching, incentives play a crucial role in stimulating educational innovations. The evidence on the returns to different kinds of skills of the students suggests that the central task of the education system is to train students in general skills. From a governance perspective, increased competition at all levels of education by providing more autonomy to the institutions and by more internationalization, and activating important stakeholders like parents and employers, seem to be important policy instruments to increase the innovative capacity of the education sector.

Executive Summary (German)

In diesem Bericht werden Aspekte der Beziehung zwischen Innovationen im Bildungs-sektor und der Innovationsfähigkeit einer Volkswirtschaft diskutiert. Die Aufgabe von Bildung ist es, kritische Kompetenzen hervorzubringen, die die Rahmenbedingungen für Innovationen in der Volkswirtschaft bilden, was wiederum Innovationen im Bildungssektor selbst voraussetzt. Der Bericht besteht aus vier Teilen. Der erste Teil befasst sich mit Innovationen in der Lehre und beim Lernen, mit einem besonderen Fokus auf neue Technologien, die den „Werkzeugkasten" der Bildung erweitern. Der zweite Teil befasst sich mit Lehrern. Der Erfolg von neuen Lehrmethoden hängt von der Fähigkeit des Lehrers ab, innovative Lehrmethoden zu entwickelnd und anzuwenden, und davon, wie Anreize geschaffen werden, um die erfolgreiche Umsetzung solcher Methoden sicherzustellen. Der dritte Teil beschäftigt sich mit Kompetenzen. Die Aufgabe von Bildung ist es, qualifizierte und innovative Schüler als Arbeitskräftepotential auszubilden. Wenn die Nachfrage nach unterschiedlichen Arten von Kompetenzen sich verändert, sollte der Bildungssektor dementsprechend reagieren. Der letzte Teil behandelt die Steuerung von Innovation und Verbesserungen in der Bildung.

Wir schlussfolgern, dass eine vermehrte Anwendung von Technologie in der Lehre kein Patentrezept für höhere Schülerleistungen darstellt und dass mehr kausale Forschung zu verschiedenen innovativen Lehrmethoden und –experimenten notwendig ist. Da der einzelne Lehrer für die Anwendung von Innovationen in der Lehre eine wesentliche Bedeutung hat, spielen Anreize eine wichtige Rolle bei der Förderung von Bildungsinnovationen. Aus der empirischen Evidenz zu den Erträgen von unterschiedlichen Arten von Kompetenzen lässt sich folgern, dass die zentrale Aufgabe im Bildungssystem ist, Schülern allgemeine Kompetenzen zu vermitteln. Aus Regierungssicht scheinen ein höherer Wettbewerb auf allen Ebenen des Bildungssystems durch mehr Schulautonomie und mehr Internationalisierung sowie die Aktivierung von wichtigen Akteuren wie Eltern und Arbeitgebern, wichtige politische Maßnahmen zu sein, die die Innovationsfähigkeit des Bildungssektors erhöhen können.

Executive Summary (French)

Ce rapport interroge le lien entre l'innovation dans la sphère éducative et la capacité d'innovation de l'économie. Le rôle de l'éducation est de développer chez les élèves les compétences essentielles pour favoriser l'innovation au sein de l'économie, ce qui nécessite des innovations dans le domaine éducatif lui-même. Le rapport est composé de quatre parties. La première traite des innovations dans l'enseignement et l'apprentissage, avec une attention particulière apportée aux nouvelles technologies qui enrichissent la palette d'outils éducatifs disponibles. La deuxième partie s'intéresse aux professeurs. Le succès de nouvelles méthodes d'enseignement dépend largement de la capacité de ceux-ci à les imaginer et à les appliquer. Des incitations pourraient donc être pensées pour encourager la mise en place de telles méthodes innovantes. La troisième partie est consacrée aux compétences. Le rôle de l'éducation est de former des étudiants compétents et créatifs à destination du marché du travail. Lorsque la demande pour certains types de compétences change, le secteur de l'éducation devrait y répondre en conséquence. La dernière partie traite de la gouvernance du milieu de l'innovation et des réformes dans l'éducation.

On peut tirer plusieurs conclusions de cette étude. Tout d'abord, l'usage de la technologie dans l'éducation ne constitue pas un idéal en soi en vue de l'amélioration des résultats des élèves. Une recherche causale plus poussée concernant certaines pratiques innovantes et expérimentations apparaît également nécessaire. Ensuite, puisque le professeur en lui-même est un élément essentiel en ce qui concerne l'innovation dans l'éducation, les incitations auprès des professeurs jouent un rôle crucial dans la stimulation des innovations éducatives. Par ailleurs, des résultats sur les rendements effectifs des compétences acquises suggèrent que la mission centrale du système éducatif doit être la formation des élèves sur des compétences générales. Finalement, dans une perspective de gouvernance, accroitre la compétition à tous les niveaux d'éducation en accordant davantage d'autonomie aux institutions éducatives et en ouvrant les systèmes éducatifs vers l'international, ainsi qu'impliquer davantage de parties prenantes telles que les parents ou les employeurs semblent être les instruments pertinents pour le développement de la capacité d'innovation du secteur éducatif.

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1. Introduction

The literature on economic growth has for a long time identified technical change as the major contributor to productivity growth (Solow, 1957). Innovations, the creation of new and improved products and new production methods that increase efficiency, are the driving force for economic growth. The education system must be capable of delivering students that are able to be innovative at the workplace. Since innovation is often related to new and improved products, high-quality education of scientists and engineers is often regarded as crucial.

This report discusses important aspects on how skill developments in education can improve the innovative capacity in the economy. Skills acquired in education are laying the basis for innovations. Improved innovative capacity in the economy requires innovation within the educational sector itself. New technologies and innovations in the education system are often thought of as drivers for better educational outcomes.

The first part of this report is on innovation in teaching methods and teaching technology. Experiments with new technologies expand the toolbox of teaching methods. Does increased computer use in teaching and learning improve educational outcomes, and what are the most promising settings for the new teaching technology? Innovations in teaching methods have to be invented and implemented by the individual teachers. The second part of the report discusses qualifications of teachers and the teacher labour market. Successful experimenting and implementations of new teaching methods depend on individual teachers' ability to experiment in smart ways, and it might be only high-quality teachers that are able to bring the best knowledge and the most relevant evidence from experiences in other schools and other environments into the classroom.

The third part of this report discusses education as a contributor to innovation in the economy. Education delivers skilled students to the workforce. Thus, it is in the form of increased skill development and improved composition of different kinds of skills that education can improve the innovation capacity of the economy. Technological improvements change the skills demanded in the labour market. When demand for skill types changes in the labour market, the education sector should respond correspondingly to ensure high employability and innovation in the economy. When production becomes more advanced, the educational sector must respond by adjusting the content, the curricula, and the learning environments.

It is obviously a complex task for policy makers to identify changes in skill needs in the labour market that are relevant for the educational system and, in addition, the potential for innovation in teaching methods. Thus, several strategies are required to ensure that schools respond properly. While competition is the fundamental premise for efficiency and innovations in developed economies, some features of education limits the potential for competition in this sector. The last part of the report discusses policies for innovation and improvements in education. Besides competition and autonomy of educational institutions, it might be important to engage stakeholders as parents and future employers in order to stimulate change and innovation.

This report builds on available quantitative research with credible identification of causal effects. In our view, results from qualitative studies by themselves can hardly be used for policy recommendations. The two main disadvantages with qualitative studies are that they have weak or no measures of the performance of students and schools, and that it is highly difficult to generalize the results.

That said, quantitative studies also have clear limitations. One weakness is that, obviously, empirical studies have to rely on data generated in the past. It is impossible to have credible analyses of the most recent changes. However, in our view, credible evidence on previous experimenting and policies is critical in order to judge and assess the potential for new experiments and future developments. Second, quantitative studies can hardly provide detailed evidence on mechanisms. We provide an overview of the evidence that we think is the most important in order to consider innovations in education. Most of these studies estimate causal effects of some intervention, without much information about which mechanisms that generate effects or which conditions that are absent in order to have positive effects. Another weakness is that innovative skills are hard to define. It involves the ability to invent smart changes. However, whether a change is an innovation is observed by successful outcomes of the innovation, which in education must be measured by improvement in some kind of skills.

2. Methods of teaching and innovation in education

Among recent innovations in the education system, the introduction of computers in classrooms is often referred to as the most significant innovation. While the physical

appearance of classrooms has not changed much since chalkboards were introduced in Prussian classrooms in the late 18th century (Konrad, 2007), the arrival of computers, tablets, and the Internet has led to the re-thinking of many traditional teaching practices and is generally seen as an opportunity for improvement (The Economist, 2013).

While this section focuses on e-learning as a group of innovative teaching and learning methods, this does not imply that other innovative methods are less effective or have less potential. Project-based learning, learning in groups, the use of games for learning and many other methods are often considered similarly innovative as e-learning. The majority of these methods are not entirely new. For example, the famous pedagogue John Amos Comenius (1630) introduced the concept of what is today often referred to as the "gamification" of education in his 17th century seminal book Schola Ludus.

From a methodological point of view, most of these innovative methods are difficult to evaluate quantitatively using observational data. One reason is that concepts like project-based learning are difficult to distinguish from other teaching and learning methods. Second, the introduction of one new teaching method is often combined with the introduction of other new methods, which makes it difficult to separate their effects. Third, the extent to which one of the methods is applied is difficult to measure. For these and other reasons, reliable empirical evidence on the effectiveness of new teaching methods is relatively scarce. Besides being one of the most disruptive innovations in education for decades, e-learning has the methodological advantage that it is more clearly distinguishable from other teaching methods and that the availability and use of computers can be more easily measured than the application of other teaching and learning methods. Although we will discuss the evidence on other innovative teaching methods at the end of Section 2.2, the majority of Section 2 will be devoted to the effects of digital and online teaching and learning.

The first part of Section 2 outlines some theoretical considerations about the effects of innovative technologies in education and points out the current state of computer use in schools. The second part of the section provides a comprehensive overview of the empirical literature on the effects of computer use in primary and secondary education. The last part presents the literature on the effects of computer use and online courses in tertiary education.

2.1. Theoretical considerations

The reasons why many researchers, policy makers and educators believe in the potential of e-learning − computer- and Internet-based teaching and learning methods[1] − are at least threefold. First, computers have the potential to allow for individualized teaching and learning. Not only the pace of teaching, but also its content can be adapted to the needs of the individual student. In 1966, it was predicted that "in a few more years millions of schoolchildren will have access to what Philip of Macedon's son Alexander enjoyed as a royal prerogative: the personal services of a tutor as well-informed and responsive as Aristotle" (Suppes, 1966, p. 201). If the "personal Aristotle" for students could relieve teachers from some of their most time consuming tasks, this might open up the potential for improvements in student achievement, without putting extra burdens on teachers.

Second, new technologies increase the transparency of student progress and allow teachers to more easily monitor and adapt to students. Without the need of manually checking homework or quizzing the class during lessons, teachers are able to track where each and every student stands.

Third, computers and the Internet have the potential to engage students more than traditional teaching methods do (Cuban, 2001, p. 15). Gamification – the use of game mechanics in non-game contexts like learning or teaching – is only one example that might make computers capable of motivating students to improve their achievement. It is also argued that specific teaching methods, for example group work, become more efficient and effective when the right new technologies are used.

These beliefs have led to high investments into computers and software in education institutions across the world. The European Union aims to equip every school with ICT equipment by 2020.[2] The most recent Programme for International Student Assessment (PISA) study shows that in 2012, the access to computers in school for 15 year-old students varies considerably across countries. While the US has a computer-student ratio of 0.95, the ratio in countries like Poland and Greece is as low as 0.36 and 0.24, respectively. Although PISA provides comparable data across countries, the absolute levels seem to be inflated when

[1] The term e-learning is sometimes used in a narrower sense. Throught this report we will refer to all digital and online teaching and learning methods as e-learning.
[2] http://europa.eu/rapid/press-release_MEMO-13-813_en.htm.

compared to national studies.[3] Nevertheless, it is clear that the number of computers per student has surged during the last decade.

It is important to note some implications of opportunity costs of investments and time use for teaching. An education production function (e.g., Hanushek, 2002) contains student input factors, like ability and family background, as well as school input factors. School inputs include the number of teachers, computers and other resources, and time spent on different teaching methods as traditional teaching and the use of computers. Education production is subject to constraints with regards to school budgets and the available instruction time. If schools decide to invest into classroom computers, they do so at the cost of not investing into other resources. If teachers decide to use innovative e-learning teaching methods, they do so at the cost of traditional teaching methods. Therefore, when one looks at investments into, e.g., computers, one should ideally compare the effectiveness of a marginal classroom computer with the effectiveness of a marginal unit of traditional school resources. When one investigates teaching methods, the interesting question is to compare the effectiveness of an additional hour of e-learning instruction with an additional hour of traditional instruction methods. Many studies that we are going to discuss do not make a careful distinction between the relative effectiveness of e-learning (taking opportunity costs into account) and the effectiveness of additional e-learning instruction.

2.2. Evidence from primary and secondary education

We identify three strands of the literature on the effectiveness of e-learning in primary and secondary education that differ along methodological lines. The first strand consists of studies that analyse cross-sectional data to describe the correlation between computer use and educational outcomes. Many of these studies focus on computer use and e-learning at home (e.g. Attewell and Battle, 1999; Fairlie, 2005; Schmitt and Wadsworth, 2006; Beltran et al., 2010; Fiorini, 2010) and generally find a positive association between home computers and educational outcomes like cognitive skills, school enrolment, or graduation rates. However, it is likely that the results of these studies are biased by omitted student and family background variables. Fuchs and Woessmann (2004) use data from PISA to show that after controlling extensively for student, school, and family background characteristics, the initial positive

[3] Specifically, PISA asks headmasters: „At your school, what is the total number of students in the <national modal grade for 15-year-old>?" and „Approximately, how many computers are available for these students for educational purposes?". These questions lead to especially high computer per student ratios if large schools have many computer labs that are open to students of all grades.

association between computer use at home and student achievement becomes negative. Fuchs and Woessmann find no effect of computer use at school on student performance.

The second strand of literature uses variation induced by government programs to identify the effect of e-learning. Angrist and Lavy (2002) exploit an Israeli government program that provided more than 50,000 computers to schools. The authors find no positive effects on student achievement. Even though the computers were given additionally to the normal school budgets and do therefore not reflect the opportunity costs that schools face when investing into computers, it is possible that computer use in instruction crowded out more effective teaching methods. Cristia et al. (2014) use a difference-in-difference setting to analyse the effects of a government program that introduced computer hardware and software to some Peruan schools between 2001 and 2006. They find no effects on grade repetition, drop out, and enrolment. Due to the use of a large administrative dataset, the authors are able to rule out even small positive effects. Machin et al. (2007) exploit a strategy change by the UK government that led some British primary schools to increase their ICT investments. They find that more ICT funding had a positive effect on student achievement for English and science, but not for mathematics. One potential explanation for the positive effects found by Machin et al. is that the schools which benefitted the most from the strategy change were schools that were initially the most effective schools. This might raise doubts about the effectiveness of computers in challenging or disadvantaged environments.

A couple of studies specifically analyse the effects of government programs that target disadvantaged schools and students. For example, Goolsbee and Guryan (2006) use variation from the E-Rate program in the US, which provided up to 2.25 billion dollar per year for better computers and Internet connections at schools and libraries. The subsidy rate per school depended on the share of students that qualified for the national free lunch program. Schools with a high share of disadvantaged students received the highest subsidies. Although the program significantly increased ICT investments at schools, the authors do not find positive effects on student performance. The studies by Leuven et al. (2007) and Malamud and Pop-Eleches (2011) use regression discontinuity designs for identification. Leuven et al. use a program targeted at Dutch primary schools with more than 70 percent of disadvantaged students and find negative but insignificant effects of extra funding for computers and software. Malamud and Pop-Eleches analyse a voucher program for students from low-income families in Romania and find that computers at home lead to lower grades, but higher cognitive ability as measured by Raven's Progressive Matrices.

A third strand of literature consists of randomized controlled field experiments on computer use in schools. While the credibility of results from randomized experiments is higher than the credibility of the results from the first two strands of literature, a majority of the experiments is conducted in developing countries and might therefore be of limited external validity for developed countries. Barrera-Osorio and Linden (2009) randomly divide more than 100 schools in Colombia into a treatment and control group. While the treatment group received computers for students and training for teachers, the control group did not. The authors find that after two years, student achievement in the treatment group slightly but not significantly exceeded achievement in the control group. Cristia et al. (2012) evaluate the effect of the One Laptop per Child (OLPC) program in 319 primary schools in Peru. They do not find positive effects on test scores in math and science, but small positive effects on other measures of cognitive skills. Mo et al. (2012) evaluate a randomized OLPC program in China and find positive effects on math test scores, but not on language test scores. While many schools in Peru did not allow students to take their computers home, Mo et al. find that the laptops were taken home in China and that computer use increased the time spent learning and decreased the time spent watching TV. Beuermann et al. (2012) conduct a randomized experiment in which 1,000 laptops were distributed to schoolchildren in Peru with the explicit aim of increasing computer use at home. The authors find no significant positive effects on cognitive skills. For the US, Fairlie and Robinson (2013) randomly distributed computers to students in grades 6-10 that did not own a computer prior to the experiment. The authors find no effect on test scores, grades, credits earned, attendance, or disciplinary actions. While students in the treatment group did not spent more time on homework, they spent more time using the computer for games, social networks and other forms of entertainment.

Several field experiments focus on the use of specific e-learning software. Banerjee et al. (2007) conduct a field experiment with about 6,000 Indian students and find that low performing students perform better in mathematics tests when they regularly use specific training software. However, it should be noted that the use of the software was partially supplemental to normal classes. This means that the results tell us little about the relative effectiveness of computer use compared to other teaching methods. Similarly, Linden (2008) conducts an experiment in India where students receive computer-based training on top of and instead of traditional class lectures. While students who use the computer instead of normal lessons perform worse than others, students who use the computer on top of normal lessons perform better than the control group. Carillo et al. (2010) evaluate the effects of mathematics

and language learning software in Ecuador. They find that students in the treatment group had higher math scores but not significantly higher language scores. Mo et al. (2012) analyse the effects of supplemental instruction with mathematics based computer games. The authors find positive effects on math test scores, although due to the supplemental nature of the field experiment, these effects say little about the relative effectiveness compared to other types of instruction.

A few randomized studies have also analysed the effectiveness of specific e-learning software in the US, Krueger and Rouse (2004) show that the use of the software "Fast ForWord" can help low performing students in the US to better solve computer-based tests, although it has no effect on other standardized language tests. Since students were taken out of classes that were not necessarily related to languages in order to receive the training with Fast ForWord, it is surprising that this at least partially supplemental language training had no effect on standardized language tests. The US Department of Education and Mathematica Policy Research (2007, 2009) evaluated six different reading and four different mathematics software products in a large randomized field experiment. Nine out of the ten products were found to have insignificant effects on achievement, while one reading software product for fourth-grade students had a positive effect. Barrow et al. (2009) conduct a field experiment with US students and find that an instructional computer program for pre-algebra and algebra had a positive effect on achievement tests on these two topics. Since the effects are larger for students from larger classes, they speculate that the higher degree of individualization made the software more effective than traditional instruction methods.

Overall, the evidence on the effects of e-learning on student performance is mixed. A large number of studies do not find positive effects, even though the use of e-learning is often additional to regular instruction. There is no evidence that computer assisted instruction can help disadvantaged students by providing them with more individualized learning material and adjustable learning speed. Among the studies that evaluate specific software products, there are some studies finding positive effects. However, it seems difficult to determine what makes these applications successful.

In a recent and comprehensive review of the economic literature on the effectiveness of computer use for educational outcomes, Bulman and Fairlie (2014) confirm the mixed results of empirical studies. The authors distinguish between studies that analyse the effects of computer use at home and studies that analyse the effects of computer use at school. Within

the latter group, they differentiate between studies on the general effects of computer investment and studies on the effects of computer use for instruction. The authors hypothesize that besides the theoretically potential positive effects discussed above, new technologies are likely to distract students and crowd out more effective instructional and learning methods.

A potential explanation for the mixed results is provided by Falck, Mang and Woessmann (2014), who compare different e-learning applications in a within-student between-subject analysis with data from the Trends in International Mathematics and Science Study (TIMSS) across countries. They find that using classroom computers for looking up ideas and information has positive effects on student achievement both in the fourth and in the eighth grade, while using computers for practicing skills and procedures has negative effects on achievement in both grades. The authors argue that when computers are used for applications that do not have equivalently effective traditional alternatives, their effect can be positive and when they are used for applications that have more effective traditional teaching alternatives, their effect can be negative. The combination of positive and negative effects that depend on the effectiveness of the respective traditional teaching methods could lead to an overall null effect for computer use in classrooms.

An important caveat to the current empirical understanding of the effectiveness of e-learning is that the technology changes quickly. The most recent developments in computer technology might yield more effective digital teaching and learning methods. Studies that were conducted some years ago are only able to investigate technologies and methods that were used at the time. For example, tablet computers are only recently introduced as educational tools in classrooms. In general, one cannot rule out that their effectiveness is different from the effectiveness of desktop computers or laptops. However, within the existing empirical literature on e-learning, there is no apparent trend of recent studies finding more positive effects than older studies. It is also questionable if more advanced hardware itself has an impact on the effectiveness of e-learning. Software and its use by teachers might have changed over time, but studies comparing different software and computer use are scarce. Since there is no clear trend in the average effect found in empirical studies, we can hardly draw evidence-based conclusions on the recent technological developments in e-learning and their effect on achievement.

Another caveat is that other types of skills than student achievement measured by test scores might be improved by e-learning. Although from a policy perspective, the effect on student

achievement is arguably most important, the use of computers can also affect a range of other educational and non-educational outcomes. First and foremost, some studies suggest that the use of computers increases computer skills of students. While Fairlie and Robinson (2013) do not find that US students with computers have significantly higher computer skills, Beuermann et al. (2012) and Mo et al. (2012) find positive effects of the OLPC programs in Peru and China on computers skills. For disadvantaged students in Romania, Malamud and Pop-Eleches (2010) find positive effects on general computer skills, but no effects on specific Internet related skills. Besides the effects on computer skills, the use of computers might also affect social student outcomes. However, Bauernschuster et al. (2014) show that broadband Internet access at home does not negatively affect students' social activities like sports, music, and art. There is not much evidence regarding the effects on other non-cognitive student outcomes.

The same holds true for teaching innovations that were introduced prior to e-learning. Unfortunately, the empirical evidence on these teaching innovations is not very large. Aslam and Kingdon (2011) use within-student variation to identify which teaching methods are most effective. The authors find that among arguably more innovative teaching methods, quizzing benefits language scores and involving pupils in discussions benefits mathematics skills. Schwerdt and Wuppermann (2011) also use a within-student between-subject identification strategy to show that traditional lecture style teaching is associated with significantly higher student achievement than teaching based on arguably more innovative problem solving tasks. Lavy (2011) uses primary- and middle-school data from Israel to show that some modern teaching practices, like endowing pupils with analytical and critical skills, have positive effects on student achievement, while other modern methods, like instilling the capacity for individual study, have no effects on achievement. Kane et al. (2011) provide evidence that between two teachers with similar traditional teaching skills, the one who also uses questioning and discussion as a teaching method, is likely to increase student achievement in reading, but not in math. Haeck et al. (2014) investigates the impact of a universal school reform in Quèbec, Canada, that transformed the teaching in mathematics from approaches of memorization and repetition to problem-based and self-directed learning. They find that the reform reduced student achievement over the whole skill distribution. In a literature overview by Westbrook et al. (2013) which has a focus on developing countries and also includes studies that are based on mere correlations, the authors emphasize the moderate quality of the majority of studies and the mixed results on the effectiveness of group and pair work, a key

practice within supposedly innovative student-centered teaching approaches. In summary, the evidence suggests that even with less innovative teaching methods than e-learning, it is anything but clear that they are more effective than traditional teaching methods.

Technology develops quickly, but empirical studies can only investigate how past experiments in teaching methods and the use of new technologies affect student achievement. It is nevertheless an important finding that economic research on e-learning finds that there is no clear-cut and generalizable answer to the question of how effective e-learning is for student achievement. The evidence clearly suggests that increased use of digital and online learning is not at all a guarantee for improved student achievement. Under some circumstances, traditional teaching methods outperform digital and online learning. More research and more experiments with credible evaluations are needed to explore the circumstances under which traditional versus innovative teaching and learning methods prevail.

It is not a surprise that experiencing with new teaching methods gives both positive and negative results, but the future development must seek to sort out the cases where the use of innovative e-learning methods outperform traditional methods. Such evidence is missing in the current research. In order to provide credible evidence on the effectiveness of new technologies, it is necessary to conduct randomized controlled field experiments with the new technology. Experimental evidence is indispensable for developing our understanding of teaching technologies.

2.3. Evidence from higher education

For university students, there are considerably fewer studies on the effects of computer use on academic performance. Fairlie and London (2012) conducted the first randomized experiment that gave free computers to college students. The field experiment was conducted with disadvantaged community college students that received financial aid. After two years, students in the treatment group were found to have better educational outcomes than students in the control group. The authors find that students that initially lived far from the campus or had jobs benefitted more than other students. This suggests that the computers provided students with some additional flexibility that improved their possibilities to learn.

One way additional flexibility can be achieved, is by courses that offer either supplemental online contents or courses that are completely Internet-based. A meta-study by the US

Department of Education (2009) identifies more than thousand studies on online education and concludes that online courses can lead to improvements in student outcomes. However, out of the large amount of studies, only 16 were experimental and only two compared online and live instruction by the same instructor. These two studies, Zhang (2005) and Zhang et al. (2006) find that students who attended a 45-minute e-learning lecture had higher achievement and higher satisfaction with the lecture than students who attended a 45-minute live lecture by the same lecturer. Figlio et al. (2013) is the first randomized study that compares a full university course provided live, with the same course (including the same instructor and the same materials) conducted online. The authors find evidence that the live-only instruction slightly dominated the online instruction and that these effects were particularly strong for students with Hispanic background, for male students and for lower-achieving students.

A recent study by Bowen et al. (2014) compare hybrid university courses with online and live elements, to live-only instructions in a randomized experiment across six universities. They find no significant differences in achievement between treatment and control groups. It should be noted, however, that neither the instruction materials nor the instructors were identical between the two lecture types. Joyce et al. (2014) also compare a hybrid course to a course with a traditional lecture format in a randomized field experiment, but hold lecture materials and lecturers constant across the two course types. The authors find slightly higher achievement for students in the traditional course and no differences in non-cognitive effort measures.

However, many argue that universities are just at the beginning of exploring the possibilities that e-learning innovations offer. For example, many universities around the world have just started to offer Massive Open Online Courses (MOOCs). These virtual courses are usually free and open to anyone who wants to participate. The design of the courses often has a focus on interactivity. Since the number of students that enrol in MOOCs is too large for conventional student-lecturer interaction, innovative online tools serve as interactive elements. Also the network that is established among MOOC students plays an important role in the course design (Waldrop, 2013). Brennan et al. (2014) present an interesting overview on how MOOCs can solve some of the current challenges in higher education.

Due to the very different nature of MOOCs compared to traditional university courses, it is difficult to evaluate their relative effectiveness. Although a few recent studies investigate implications of MOOCs from a theoretical perspective (e.g., Acemoglu et al., 2014; Hoxby,

2014), there is very little empirical evidence on the topic. Banerjee and Duflo (2014) use data from an economics MOOC at MIT and provide some insights into the important roles of self-discipline and focus for successful MOOC participation. To our knowledge, Griffiths et al. (2014) is the only study that compares MOOCs in hybrid and purely online settings on a popular MOOC platform with traditional university courses. After controlling for student backgrounds, the authors find that students enrolled in hybrid MOOCs did at least as well as students enrolled in traditional courses. In order to draw robust conclusions on the relative effectiveness of MOOCs, randomized field experiments would be desirable. Until then, it remains an open question how effective MOOC innovations in tertiary education are for student learning.

3. Qualifications of teachers

The teachers are responsible for the learning environment in class. The main potential for innovation in education is in the classrooms. Students' skill development depends on a variety of other factors, but teacher behaviour can more easily be affected by policy interventions and school principals than most other factors.

Productive innovations in the classroom require teachers that are willing and able to accomplish smart experimenting. Unfortunately, innovative skills of teachers and students are hard to define and can hardly be directly observed. It includes the ability to invent smart changes, but whether a change is an innovation can only be observed by improvements in some skills of the students. Since innovation processes include experimenting, there will necessarily be some failures during the process. This is probably the reason why innovative skills are not measured in the empirical literature and why the literature focuses on teacher quality measured by teachers' value-added on student achievement. It is must be the case that high-quality teachers measured the way it is in the literature use the most efficient teaching methods. Thus, it is plausible that it is the high-quality teachers who are most able to judge what will be smart experimenting, and also most able to bring the best knowledge and the most relevant evidence from experiences in other schools and other environments into the classroom. High-quality arguably is a pre-condition in order to be able to innovate. However, it is an important caveat that some teachers with observed high value-added for their students might be adaptive and rely on others' experimenting behaviour. Since experimenting fail from

time to time, and the failures will turn out as low value-added for the students, teacher quality as measured in the literature cannot perfectly map innovative teachers.

A voluminous research literature from the US finds large variation in teaching quality across teachers (Hanushek, 2011, Jackson, 2012, Chetty et al., 2013). The evidence on which teacher characteristics improve student performance the most is more mixed, but some studies find that teacher's test scores are positively related to student achievement.

This section first provides a discussion of the empirical evidence on teacher quality with a focus on teachers' objectively measured skill levels. The second part discusses policy implications for the teacher labour market and for recruitment practices to teacher education.

3.1. Teacher quality

The literature on teacher quality estimates the individual teacher's contribution to student achievement in a value-added framework. This method measures the average improvements in student test score during a given period of time, typically during one school year, for the students of a given teacher. The literature finds that some teachers have consistently high value-added of their students, while others have consistently low value added of their students Rivkin et al., 2005; Rockoff, 2004). The evidence clearly indicates that this variation in teacher quality is real. For example, Kane and Staiger (2008) find that the value-added measures strongly predict a teacher's future success in the classroom; Jacob and Lefgren (2008) find that they are correlated with school principals' subjective evaluations of teachers; Koedel (2008) finds that they affects the likelihood that a student will drop out of high school; and Chetty et al. (2013) find that high-quality teachers in primary education increase the probability of college attendance and increase earnings.

Jackson (2012) analyses teachers in the 9^{th} grade and concludes that teachers have even larger effects on behavioural outcomes as absence and suspension than on traditional test scores. The teacher effects on cognitive and non-cognitive outcomes are only weakly correlated, which implies that the skills inherent in teacher quality are different for different types of outcomes. In addition, Jackson finds the teacher quality with respect to non-cognition predicts future outcomes over and above teacher quality with respect to cognition. For example, the former has a stronger impact on the probability to drop out of high school than the latter.

Overall, this literature indicates that the impact of teacher quality is of about the same magnitude as the impact of parental background, and in addition, that the importance of

teacher quality decreases as the students' progress through the educational system. Unfortunately, to the best of our knowledge, this literature only includes studies from the US.

The main policy questions are: (i) what characterizes teachers that are able to give the students a high value-added in achievement; and (ii) how can incentives improve teacher quality? Regarding (i), high-quality teachers are presumably innovative. They constantly search for better teaching methods and test new ways of teaching. Innovative teachers adjust teaching methods to the composition of the class and to the level of initial skills in the class. They are more open to innovative thinking by students and do not rigidly stick to the curricula, but react on changes in the outside world. They are able to use efficient teaching methods adjusted to characteristics of the class and individual pupils. Smart teachers are better able to use innovative teaching methods, and we would expect smart teachers to have high observable skills.

Innovations and innovative skills of teachers are very difficult to measure. We therefore focus on more observable characteristics of the teachers in the rest of this section.

While it in general has turned out to be difficult to relate the variation in teacher quality to objectively measured characteristics of the teachers, some empirical evidence from the US suggests that students have better outcomes when their teacher graduated from the more selective colleges and have high test-scores on teacher license examinations (Ehrenberg and Brewer, 1994, 1995, Hanushek and Rivkin, 2006, Goldhaber, 2007, Jackson and Bruegmann, 2009, Kukla-Acevedo, 2009, Clotfelter et al., 2010). The positive impact of having graduated from selective colleges is arguable related to stricter admission requirements.

Grönqvist and Vlachos (2014) are able to match student-teacher data for Sweden, and investigate the effect of different measures of teacher skills. They exploit measures of cognitive and social interactive abilities from military enlistment, covering essentially the entire male population. In addition, they use the grades of the teachers at their last year of compulsory education (GPA). They find relatively small average effects of these skill measures, but important heterogeneities. It seems to be strong positive effects of male teachers' GPA, but not for female teachers GPA. Interestingly, they find that higher cognitive skills at the military enlistment increase the achievement gap between high and low aptitude students of the teacher, while higher social abilities reduce this gap. A recent study for the Danish Productivity Commission investigates the relationship between teacher test scores and student test scores at the school level (Produktivitetskommissionen, 2013). They find that the

average of the teachers' grades on their exams in high school is positively related to the test scores of their students in lower secondary education.

In a recent paper, Hanushek et al. (2014) investigate the effect of teacher cognitive skills using international data. They use measures of teachers' skills in numeracy and literacy from the recent PIAAC study from OECD and student achievement in mathematics and reading in the PISA-study. Using different empirical approaches, they find that teacher cognitive skills are an important determinant of international differences in student performance.

The attractiveness of the teacher education and the teacher profession is therefore crucial. Are high-achieving students with high test scores choosing to become teachers? Nickell and Quintini (2002) address this question by using data from England on a standardized achievement test for students aged 10-11. They compare the percentile position of teachers born in 1958 and in 1970 at this test, and find that the test score percentile rank for males fell from about 76 for the cohort born in 1958 to about 65 for the cohort born in 1970. However, they find no decline in the test score rank for females. Fredriksson and Öckert (2008) and Grönqvist and Vlacos (2014) find a similar decline for Sweden, and Møen et al. (2012) find similar changes Norway. Fredriksson and Öckert investigate test scores at age 13 for those who later decided to pursue a teacher education and serve as a teacher, without distinguishing between females and males. They find that the average ability rank of the teachers fell from the 68^{th} percentile in the cohort born in 1948 to the 58^{th} percentile for the cohort born in 1977. Salvanes et al. use cognitive tests at age 18 for teacher education students. For males they find that the ability rank fell from about the 72^{th} percentile in the cohort born in 1950 to about the 60^{th} percentile for the cohort born in 1977, and their analysis indicates the same development for females. The evidence is similar for the US and Australia (Corcoran et al., 2004; Hoxby and Leigh, 2004; Leigh and Ryan, 2008).

Unfortunately, to our knowledge, causal evidence on which kind of teaching methods that yield the highest student achievement is missing in the literature, see also the discussion in Section 2. This would be highly valuable in order to provide direct advice on teaching methods under specific contexts.

What kind of teachers do the schools need in order to make efficient use of innovative teaching methods? The evidence above indicates that the answer is partly teachers with high measured skills. However, the question is at odd with a large number of studies that find that teachers respond to incentives. Better questions are what kind of incentives do teachers need

in order to strive for improved teaching methods, and what kinds of incentives must schools provide in order to be attractive for high-quality and innovative teachers.

3.2. Implications for the teacher labour market

The evidence above implies that the recruitment policy of teachers is crucial for overall teacher quality. Schools need to be attractive employers in order to attract innovative teachers, and they must undertake critical considerations of applicants to vacant positions.

The available empirical evidence indicates that teacher behaviour is similar across countries. This is, e.g., the case for turnover behaviour and mobility across schools (Falch and Strøm, 2005, for Norway; Karbownik, 2014, for Sweden; and Barbieri et al., 2011, for Italy), although the share of teachers leaving for other jobs is lower in countries with centralized institutions like in Italy than in countries with more decentralized institutions like Scandinavia and the UK. However, recruitment behaviour of schools and local governments depends on institutions.

The institutions of the teacher labour market and teacher education differ across countries. While teachers in the US are typically educated from regular universities, the Nordic countries have traditionally had specific teacher colleges that enrol students directly from upper secondary education. The study programs are explicitly designed for a teacher career, including practical training. The hiring of teachers is mainly in the hands of individual school principals in these countries. In several other European countries, the decision-making is more centralized. Hiring decisions for teachers are made on the state or federal level in several countries, including Italy, France and Germany (see for example Barbieri et al., 2011), leaving much less leeway for local policies in the local governments and in the schools.

Naper (2010) finds for Norway that decentralizing the recruitment process from the municipal level to the schools increases school effectiveness. Similarly, Hensvik (2012) for Sweden and Hoxby (2002) for the US find that private schools to a larger extent that public schools hire teachers who lack formal skills but who are of higher ability. This evidence suggests that decentralized recruitment and accountability at the school level are important conditions for recruitment processes that actively search for high-quality and innovative teachers.

One main recruitment instrument in the labour market is the wage. In most countries, the teacher wage is almost exclusively determined by experience and formal education. Teacher unions are visible in public debates, seem influential, and take part in collective bargains. The

literature finds that schools increasing the wage improve their recruitment of teachers. For Norway, Falch (2010, 2011) exploits a system with wage bonuses to identify the wage response of teachers, and Clotfelter et al. (2008) investigate a similar bonus system in North Carolina. Individual schools can use wages strategically to increase the number of teachers interested in working at that particular school, if they are allowed do to so in the prevalent institutional rules. This is clearly an argument for flexibility in wage setting at the school level to the extent that teacher supply varies across schools. In fact, the actual interventions investigated by Falch (2010, 2011) and Clotfelter et al. (2008) were motivated by teacher shortages. By allowing wages to vary across schools, one should be able to attract better teachers to schools in deprived neighbourhoods, rewarding their extra effort or compensating for negative amenities.

Sweden introduced wage flexibility not only at the school level but also at the individual level in the 1990s. Hensvik (2012) finds, surprisingly, that the decentralization of the wage setting did not change the overall distribution of teacher wages across teachers. This finding might be a result of teacher unions, which seem to be important players in these local bargains. However, she finds that the teacher wage in the local labour market is responsive to competition. Entry of private high schools increases the average wage in public high schools. She finds that the wage increases first and foremost for novice teachers and teachers in fields with the most severe shortages such as math and science teachers. In addition, the competition is also associated with a stronger link between wages and teachers' cognitive skills. Although the effects estimated are relatively small, they indicate that a compressed wage structure and low wage responsiveness to teacher quality are at least partly a result of weak external pressure.

Another type of wage flexibility is performance pay, which might take the forms of bonuses to innovative teachers or to teachers with high value-added for their students. Using PISA data, Woessmann (2011) find a positive association between teacher performance pay and student achievement. Figlio and Kenny (2007) use survey data from the US and find that test scores are positively related to individual financial incentives to teachers for good performance. These studies capture both the incentive effects of performance pay in addition to other potential mechanisms such as selection effects on the quality of teachers. Unfortunately, there is only limited evidence from experimental studies on performance pay in Europe. Atkinson et al. (2009) investigate the introduction of performance pay in England

in 1999 within a value-added framework. They find a clear positive effect on student achievement.

Before being recruited by schools, teachers themselves must go through the education system. The Finnish experience is in accordance with the understanding that recruitment of high ability individuals to the teacher profession is highly important. In the early 1980s, Finland performed in line with other countries in internationally comparable tests for students in lower secondary education conducted by The International Association for the Evaluation of Educational Achievement. 20 years later, Finland outperformed the other countries in the first PISA tests. During the same period, there has not been a decline in the attractiveness of the teacher education, contrary to the evidence from other countries. Teacher education programs are still among the most popular studies, where only the very best students from upper secondary education are admitted. The tricky question is why a teaching career has continued to be among the most popular professions in Finland, in contrast to most other countries. It is challenging to establish scientific knowledge on this issue because Finland differs from other countries in a number of ways. For example, access to higher education has always been restrictive in Finland; there were major reforms in teacher education in Finland during the 1970s and 1980s, introducing among other things a mandatory master degree for teachers and reducing the number of teacher education institutions; and there was a severe recession in the Finnish economy in the early 1990s in the aftermath of the breakdown of the Soviet Union.

It is clearly challenging to establish strong evidence on what constitutes high-quality teacher education. The evidence summarized above indicates that teacher's skills prior to choosing teacher education are important, which suggests that the attractiveness of teacher education is a crucial prerequisite. However, there is limited evidence on how the attractiveness of teacher education and the teacher profession more generally can be increased. Probably it is important to think in terms of the working conditions of teachers. If the working conditions in general are considered to be poor relative to other professions that require higher education, one cannot expect to recruit high-ability students to the teacher education. The pay system and other working conditions for teachers should be in the forefront of the governments' policies to increase teacher quality. One challenge is that changes in the teacher labour market require support from teacher unions, which have a more short-sighted objective (Moe, 2011).

4. The need for innovation in education

The demand for different types of skills in the labour market depends on industrial structure and the applied technology. The increased intensity in the use of information technologies has changed the way workers and organizations operate and communicate, and changes in international trade patterns have implications on the type of production. The educational system must respond to such changes and adapt to the needs of the labour market.

Innovations have many facets, but are most often related to technological improvements. One might argue that scientific skills, in particular in technology and natural sciences, are of increasing importance for the innovative capacity of economies in a globalized world. The main basis for such skills is education in mathematics and science. One might also argue that the implementation of new technologies and innovative ways of organising the production require a broader set of skills than those related to specific subjects in the educational system.

The role of education is skill development of the students. This section is on what kind of skills is rewarded in the economy. Since the most valuable workers for firms are those who are able to innovate and to adapt to new technologies and other innovations, this is the most direct way of investigating the need for innovation in education. If mathematical skills are highly rewarded in the labour market, changes that improve such skills are important innovations in education.

This section firstly presents evidence on the return to ICT skills in the labour market. Thereafter the importance of general skills in mathematics and science and non-cognitive skills are discussed.

4.1. ICT skills

In the 1990s, a literature initiated by Krueger (1993) on the return to computer skills emerged. This literature finds a clear positive association between wages and computer usage at the workplace, see also DiNardo and Pischke (1997) for Germany, Oosterbeek (1997) for the Netherlands, and Arabsheibani et al. (2004) and Borghans and ter Weel (2004, 2011) for the UK. However, several studies conclude that these associations merely reflect unobserved heterogeneity rather than a causal effect of skills in the new technology. Oosterbeek (1997) finds that the wage is unrelated to the intensity of computer use, and argues this indicates that it is not a causal effect of computer use on wages. DiNardo and Pischke (1997) argue that the association probably is spurious because they find a similar relationship between wages and simple tools as the use of pencil on the job. Borghans and ter Weel (2004) find that the wage

is unrelated to a proxy of computer skills, conditional on computer usage, in contrast to the ability to write and to carry out mathematical procedures. Borghans and ter Weel (2011) find that high intensity of computer usage among skilled workers is not a result of high skills, but rather a matter of cost efficiency related to high wages. Likewise, low computer usage of relatively unskilled workers does not seem to be a result of skill deficiencies. Computers seem to substitute for routine activities, which subsequently lead to skill upgrading (Borghans and ter Weel, 2007).

This literature should not be interpreted as evidence that specific ICT skills per se are important for efficiency and technological change. Rather, it suggests that computerization makes firms able to use high-skilled and high-wage workers more effectively. When new technology gets cheaper, a larger share of the workforce gets access to the technology. New technology is introduced for high-wage workers to reduce costs, which subsequently leads to skill upgrading and is spread to other workers via training on the job as the price of the new technology declines and its suitability improves.

One implication of this evidence is that it is not the role of the education system to train the students in using specific tools at the workplace. If, however, computer skills have increasingly become a general skill that is not related to specific tasks in the labour market, their relationship with wages and employability might have changed over the last few years. In addition, the literature has not investigated the effects for specific groups of workers, as for example workers with vocational education, for which there might be some positive impacts despite a very low average impact across all workers.

4.2. The importance of mathematics and science in school

Cognitive skills are associated with intelligence and the ability of problem solving. A number of papers have investigated the impact of test scores in mathematics and science on earnings and other individual outcomes. For example Bishop (1989), Murnane et al. (1995), and Altonji and Pierret (2001) find that measures of achievement in these subjects are important determinants of individual earnings for given educational attainment and observed individual and family characteristics. Koedel and Tyhurst (2012) use a different approach to reach the same conclusion. In a resume-based field experiment where they submitted fictitious applications on job openings, they find that employers are more likely to respond to resumes that indicate stronger mathematical skills.

A strand of literature on the effect of school curriculum on educational and labour market outcomes initiated by Altonji (1995) is summarized in Altonji et al. (2012). These studies typically ask to what extent earnings depend on the number and levels of mathematics and science courses taken in high school. For the US, Altonji (1995), Levine and Zimmerman (1995), and Rose and Betts (2004) generally find a positive impact on earnings of taking more mathematics and science courses. It is questionable, however, whether these estimates can be interpreted causally or whether they represent selection effects into different coursework. Various instrumental variables for coursework choice are used in this earlier literature, but these identification strategies can be criticised (Altonji et al., 2012).

If the effect of skills in mathematics is as strong as these studies indicate, even small interventions that increase mathematical skills should have non-negligible effects. Some recent European studies apply more credible strategies to identify the impact of curriculum and training on earnings. Joensen and Nielsen (2009) exploit a pilot scheme implemented in some Danish high schools, in which students were allowed to select additional combinations of high school courses. The pilot scheme introduced exogenous variation across schools in choice possibilities which made it easier to choose the course in advanced mathematics. Using an instrumental variable method which arguably control for selection of students, they find that taking more advanced mathematics courses has a significant and sizable positive impact on earnings. Their results imply that one extra course in advanced mathematics increases earnings by 20-25 percent. The main mechanism of this effect on earnings seems to be the increased likelihood of taking higher education.

Joensen and Nielsen (2014) investigate gender differences using the same pilot scheme. They find that the effect in Joensen and Nielsen (2009) is driven by girls. The marginal effect of more mathematics courses is strongly positive for girls, but insignificant for boys. This result suggests that there is a lost pool of mathematics talent among high ability girls. Changing the institutional rules such that courses in mathematics get more accessible and interesting for girls will increase the productivity of the economy. In the Danish case, the old system seems to have put too much restriction on the combination of different courses in order to allow the students to take the most advanced course in mathematics.

Falch et al. (2014a) exploit a rather different quasi-natural experiment from Norway to shed light on the importance of mathematics. At the end of compulsory education in Norway, at age 16, about 40 percent of the students are randomly selected to a high stake external exit

examination in mathematics, while the rest of the students have an examination in Norwegian or English language. The students are informed of their exam subject 2-5 days in advance, such that there is a period of intensive preparation with extensive support from teachers. This intervention is an intensive training and preparation period in either mathematics or languages, followed by a high stake test in either of these subjects. Falch et al. (2014a) consider the training part of the treatment to be most important for the outcomes they study: dropout from high school, enrolment in higher education, and enrolment in natural science and technology education. They find positive and nontrivial effects on all outcomes. The treatment seems to affect students across the whole ability distribution, although at different margins. The positive effect on high school graduation is mostly related to improved progression for students initially enrolling in vocational study tracks in high school. These students have typically relative low prior skills. On the other hand, the positive effect on enrolment in science and technology programs in higher education is driven by students with relatively high skills in mathematics prior to the treatment. For these students, the treatment also seems to have a positive effect on grades in mathematics in high school. Gender seems to play a smaller role than in the Danish experiment. Contrary to the Danish case, the effects seem to be somewhat stronger for males than for females, but the gender differences are relatively small and interact with prior skills in mathematics.

It is intriguing that that such a short training period can have a significant impact. However, the results are in accordance with descriptive evidence on the importance of different kind of skills for the same student population, see Falch et al. (2014b). In addition, recent experimental studies suggest that effects of rewards and interventions are more pronounced for math tests than for reading tests, see Bettinger (2012), and that student behaviour is short-sighted, see Levitt et al. (2012).

Some recent studies from the US also find strong causal effects of mathematics. Some studies investigate the effect of accelerating the teaching in algebra, holding total school hours fixed. Cortes et al. (2014) studies an algebra policy where students with low achievement in an eighth grade exam in mathematics were assigned to algebra courses with double instructional time in ninth grade. They find positive effects of this double-dosing of algebra on high school graduation rates, college entrance exam scores, and college enrolment rates. In accordance with the findings by Falch et al. (2014a), the intervention seems to have been most successful on these outcomes for students with relatively low initial skills. Other studies from the US on

the same issue find similar effects (Goodman, 2012; Nomi and Raudenbush, 2013; Taylor, 2014).

The literature applies different identification strategies, but all studies typically find sizable effects of increased coursework in mathematics during the school year, even though the increased coursework in mathematics is at the expense of coursework in other subjects. Individuals exposed to increased training in mathematics and science achieve higher success in education and in the labour market.

4.3. The importance of non-cognitive skills

The literature on the role of cognitive skills has been challenged by a literature arguing that some of the associations with cognitive skills capture the impact of non-cognitive skills. The insight above does not imply that also other types of skills than cognitive skills might improve employability and wages. Like ICT skills, non-cognitive skills are not related to specific subjects in school. Non-cognitive skills are attributes that are not measured by achievement tests or IQ tests and go under different labels, including personal traits and character. A popular taxonomy of non-cognitive skills is given by the five-factor model shaping human personality: agreeableness, conscientiousness, emotional stability, extraversion and autonomy. There is a large literature in psychology on such skills, which has later raised the interest of economists and educationalists. Recent summaries of the literature include Brunello and Schlotter (2011) and Heckman and Kautz (2013).

The evidence suggests that the self-reported traits 'conscientiousness' and 'emotional stability', together with cognitive skills, are most important for success in education and in the labour market. Some recent studies use more objectively measured information on non-cognitive skills and reach the same conclusion (Lindquist and Vestman, 2011; Segal, 2011; Falch et al., 2014b). Lindquist and Vestman use a measure of non-cognitive ability from a personal interview conducted by a psychologist in the military enlistment in Sweden, the same test as exploited by Grönqvist and Vlachos (2014). The judgment is meant to capture skills that are considered important in the military, as the ability to socialize with others, to cope with stress, to show up on time, and to be able to deal with criticism and failure. They find that men with high risk of unemployment and low earnings lack these non-cognitive skills rather than cognitive skills. Falch et al. distinguish between performance in mathematics/science and in behavioural and practical subjects in Norwegian schools, and find that the former is most important for the probability of college enrolment, while the latter is

most important to avoid welfare dependence. Segal finds that for US men both test scores and misbehaviour in eighth grade predicts earnings.

Non-cognitive skills are also malleable in school ages, see Heckman and Kautz (2013), and seem particularly important for labour market participation. However, the evidence on how the education system might improve traits such as conscientiousness, emotional stability, and self-management is weak.

5. Conditions for quality and innovations.

Competition is the fundamental premise for efficient use of resources and economic growth in developed economies. Firms that are able to innovate increase their profit and expand their markets. Innovative activity has the best conditions under external pressures from customers and other market participants in combination with intrinsic motivation within the enterprise. This mechanism is the same for education as for other industries. Schools facing competition have stronger incentives for innovation.

Competition can be viewed as an accountability device. If the enterprise does not deliver products as expected, it will lose customers and profits, and go bankrupt as the utmost consequence. If the competition is weak, other accountability devices must replace competition in order to achieve the external pressure that is necessary for innovation and efficiency. Competition and accountability requires autonomous schools.

Planning and instruction are alternative models to competition and accountability. Efficiency by use of such governance systems does, however, require detailed information of the production process. In education, the production function is clearly very hard to observe for outsiders. Clearly, the need for innovation is a recognition that teaching methods can be improved, but without knowledge on how. This is even more obvious in higher education where education and research are partly integrated processes. There is a severe information problem with respect to school quality. While this is a major challenge for educational governance with planning and control, it also limits the efficiency of competition in educational markets.

This section firstly presents evidence on the effect of competition and autonomy in education. One presumption for competition is autonomy to react to changes in demand. As for other

markets we expect competition to improve innovation and efficiency. This is, however, an empirical question because the market for education might have many imperfections. For example, the quality of individual schools and universities can be hard to observe for parents and students. Thereafter we discuss the role of accountability and stakeholders when the degree of competition is low.

5.1. Competition and autonomy

The advantage of competition is the main argument for school choice and vouchers as suggested in the seminal book by Friedman (1962). At the compulsory level, market mechanisms have been introduced over the last decades in several countries. The most extreme change is probably the voucher reform in Chile in 1981. The government began to provide vouchers to any student that attended a private school, and tied the budget of public schools to their enrolment, see Hsieh and Urquila (2006). After the reform, the private enrolment rate doubled to 40% during seven years. Hsieh and Urquila evaluate the effect of the reform by investigating the change in educational outcomes in communities with large demand for private schooling compared to communities with low demand for private schooling. They find that this large introduction of market forces did not affect student test scores and other educational outcomes.

In the US, charter schools have been introduced over the last two decades. Charter schools are private school with considerable public funding and freedom from many of the constraints under which traditional public schools operate. For example, charter schools are not restricted by collective bargaining agreements with teacher unions that are binding for regular public schools. The charter school system allows for, e.g., a larger diversity of educational approaches and increased competition. The evidence indicates that charter schools have introduced competitive forces into the education market. Charter schools seem to reduce the transaction costs of switching schools (Hanushek et al., 2007), and low student test scores significantly increase the probability of school closing (Schwenkenberg and Vanderhoff (2014).

The evidence indicates, however, that on average, charter schools do not necessarily deliver better test scores than traditional public schools. Some studies find no effect on student test scores (Booker et al., 2007; Hanushek et al., 2007; Gleason et al., 2010), while others find small positive effects (Chakrabarti, 2008; Figlio and Hart, 2014). In addition, it seems like

charter schools have a positive effect on behavioural outcomes such as the graduation rate and incarceration, see Booker et al. (2011).

There is variation in the quality of charter schools, as demonstrated by some school closings on the one hand and oversubscribed schools on the other hand. The oversubscribed schools are presumably of high quality, at least in the consideration of the students and parents. Indeed, studies on oversubscribed high schools find that winning the lottery and being admitted improves both student achievement and behavioural outcomes (Abdulkadiroğlu et al., 2011; Dobbie and Fryer, 2013).

Sweden implemented a radical voucher reform in 1992, where private schools get basically the same funding as public schools. The share of students enrolled in private schools increased slowly during the first years after the reform, from about 1% in 1992 to about 4% in 2002 and to about 11% in 2009. The evidence on the effect of this reform is also mixed, see the overview of the literature in Böhlmark and Lindahl (2012). Böhlmark and Lindahl investigate whether the change in students' educational performance in Swedish municipalities depends on the increase in the share of students in private schools in the municipality. They find a positive effect on both test scores and long-run educational outcomes. However, these effects are for most outcomes statistically significant only about a decade after the reform.

One reason why increased competition in compulsory education seems to have limited effect on school performance is probably that it does not by itself eliminate the information problem. If students and parents are expected to make good choices, they need to have reliable information about school quality. This seems to have been a major obstacle in the Swedish case, where there is no public information on objective measures of student achievement. In addition, students and parents are likely to be interested in a variety of other factors at schools, not only their capacity to provide high test scores. If parents care about, e.g., cultural activity and behavioural skills, one should expect that schools also would compete along these dimensions.

Besides competition among schools, it is often argued that school autonomy can increase student achievement. Decentralization puts management decisions into the hands of decision-makers who potentially have better knowledge about local demands and educational processes. Innovation requires discretion to change in unforeseen directions. Arcia et al. (2011) provide an overview of the literature on school autonomy and conclude that while

policies that aim at increasing school autonomy in Latin America have generally not led to higher student achievement, European policies resulted in more promising effects, see also Falch and Fischer (2012). For example, Barankay and Lockwood (2007) use data from Switzerland to show that more fiscal decentralization is associated with higher educational attainment on the canton level. In the UK, the introduction of Grant-maintained (GM) secondary schools was a very explicit policy to increase school autonomy. During 1988-1997, almost 1000 schools opted for the GM status after majority rule in a voting procedure among parents. Clark (2009) exploits this rule in a regression discontinuity framework, and finds large positive effects of GM status on school pass rates on standardized examinations. The introduction of GM school increased the competitive pressure on other schools, but Clark finds no effect on the performance of neighbouring schools.

In an attempt to explain differences in effects of school autonomy for various countries, Hanushek et al. (2013) suggest that school autonomy works better if there is external accountability in place that limits opportunistic behaviour of schools. Since accountability is more often institutionalized in developed countries, school autonomy reforms have more positive effects in these countries.

In higher education, competition and autonomy are more prevalent than in compulsory education because student enrolment is not restricted to catchment areas. Aghion et al. (2010) argue that competition and autonomy cannot empirically be disentangled in higher education because, in practice, they scale up and down together. It seems pointless to promote competition among universities without autonomy, and autonomy can only be valuable if universities compete with each other. Aghion et al. use performance on university rankings, which mainly measure research and patent activities, as outcomes in their analysis. They find clear evidence that increased competition and autonomy increases university performance. The challenge for investigating educational outcomes in higher education is to collect performance on a comparable scale across institutions. Anyway, it seems pretty clear that students prefer universities with a high reputation in research. Aghion et al. show that US universities perform better than European universities, and that competition and autonomy is stronger in the US. They also show the same correlation among European countries and among US states. For the US, they also provide causal evidence, by use of information of legislative committees in the states as instruments, and find that autonomy and competition enhance the productivity of expenditures by research universities.

A way to increase competition among universities is the internationalization of education. Especially in small countries with few research universities, the competition among the universities might be weak. Facilitating the international mobility of students and faculty would increase the competitive pressure in such cases.

Causal evidence on the effect of competition on the use of new technologies does, to the best of our knowledge, not exist. Such evidence would improve our understanding of why competition and autonomy sometimes improves student achievement and sometimes not.

5.2. Stakeholders and accountability

An alternative to competition in order to enhance innovation in schools is to introduce accountability systems like the US 'No Child Left Behind' (NCLB) program. In accountability systems, the government measures the performance of each school, and there are consequences related to the performance. The consequences might be weak, such as making the information publicly available, or strong, such as closing schools with low performance. The evidence regarding NCLB indicates that the reform had a positive but modest effect on student achievement, see Dee and Jacob (2011). While the reform clearly is related to student achievement and provide information to the public, the limited effect might be related to the fact that the reform does not itself introduce market forces to allow the actors to fully react on the information.

Burgress et al. (2013) investigate the effect of abolishing school performance tables in Wales. From 1992 to 2001, secondary school performance tables were published annually with high public recognition in both England and Wales. They presumably inform parents about school quality. The Welsh Assembly Government abolished the publication of these tables in 2001. In a difference-in-difference analysis comparing the development on national testing in England and Wales, Burgress et al. find that this reform markedly reduced school effectiveness in Wales relative to England.

Another accountability mechanism is direct involvement of stakeholders. In principle, there are two possible channels of influence: 'exit' or 'voice'. With 'exit', the actor vote with their feet and leave situations in which they are unsatisfied. This is the traditional competition mechanisms. With 'voice', the actor tries to have an impact by other means. This is an important role of stakeholders. One important channel might be to provide schools with information that is hard to collect by other means, but it might also be to provide pressure in

specific directions. For example, employers are important stakeholders at all educational levels because they ultimately will be the beneficiaries of the skills acquired in education. They can provide information on what kind of skills they consider important in a long-run perspective that is hard for schools and universities to gather in other ways.

In compulsory education, parents are important stakeholders. It is costly to move to another school, in particular when school catchment areas are strictly enforced. Educators are concerned about lack of parental involvement in their children's education and it seems to have been an apparent decline in parental involvement, see for example Mapp et al. (2008). A large literature mainly in pedagogy and sociology find evidence of a positive relationship between parental involvements on student achievement, see the surveys in Jeynes (2012) and Wilder (2014). It is clearly severe selection problems in observed parental involvement which is challenging to handle in empirical analyses. Parents who are most engaged in their children's development will also engage the most in school activities.

In an interesting study from Paris, Avvisati et al. (2014) analyse a randomized experiment. Parents of children in the 6^{th} grade were invited to participate in a simple program of parent-school meetings on how to get better involved in their children's education. The program consisted mainly of a sequence of three meetings where only parents were invited and not their children. The sessions focused on how parents can help their children by participating at school and at home in their education and offered parents advice on how to adapt. They find that pupils of treatment classes developed more positive behaviour and attitudes in school. However, test scores did not improve under the intervention. While the results of this experiment are intriguing, they are mainly effects of schools engaging parents, and not on the effect of parents engaging schools. Although this is very different from external pressure, it constitutes an important policy tool for schools and policy-makers.

6. Conclusion

Economic growth requires that the supply of high-skilled labour continues to rise. The main role of the educational system is to deliver skilled students to the workforce.

In this report we assert that innovations in teaching methodology towards a more intensive use of computers and e-learning have not universally increased student achievement. The evidence also clearly suggests that ICT skills themselves are not rewarded in the labour

market. Instead, the labour market mainly rewards basic skills in mathematics and science, in addition to non-cognitive skills like personal traits and character. Cognitive skills seem to be of major importance for advanced and innovative economies, and can be fostered by more intensive teaching. A more open question is how non-cognitive skills can be stimulated in an educational setting.

Innovations in teaching methods require teachers that are able to innovate. Excellent teachers are able to motivate students and to choose the most productive teaching method for each specific topic. A challenge for many European countries is to provide incentives for high-ability students to choose the teaching profession, and to incentivize teachers in schools to improve their teaching. We argue that many policies can stimulate such changes and thus increase the innovative capacity of the educational system, such as introducing more flexibility in the teacher labour market, increasing competition forces at all levels of education by providing more autonomy to the institutions and more internationalization, and activating important stakeholders like parents and employers.

OECD (2014) has initiated an effort to measure innovation in education. The challenge of efforts like this is to disentangle true innovations from changes that can be detrimental to student achievement. At present, the knowledge on which new teaching methods and school organizations improve educational performance is limited. Before starting to measure innovation, it is necessary to establish evidence-based knowledge on what characterizes true innovations. The possibility to use randomized or quasi-randomized experiments to identify true innovations should be exploited to a much larger degree than today. Many of the analyses cited in this report give well-founded guidance on how greater insights in true innovations can be achieved.

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