Review Article

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Non Vitae Sed Scholae Discimus? Schooling Fosters Intelligence

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Abstract: Intelligence is important for success in school. But does schooling also impact intelligence? In this review, we present evidence showing that both the amount and the quality of schooling affect intelligence test performance. Besides, differential effects are addressed. The schooling effect is stronger for academic than for non-academic tracks, shows for different types of intelligence and for different age groups, although it might be stronger for younger children. However, obtaining this state of knowledge has been anything but trivial, given that the duration of school attendance is highly confounded with age effects on intelligence, and that different tracks of schooling comprise a selective intake of students. Therefore, this review also presents methodological solutions that have been applied to these problems. Finally, we outline that the schooling effect on intelligence test scores is not an artifact but primarily due to a "real" enhancement of intelligence.

Keywords: Duration of school attendance, effects of schooling, general vs. specific abilities, intellectual development, quality of schooling

Zusammenfassung: Intelligenz ist wichtig für schulischen Erfolg. Fördert Beschulung jedoch auch die Intelligenz? In diesem Übersichtsartikel präsentieren wir Evidenz dafür, dass sowohl die Schulbesuchsdauer als auch die Beschulungsqualität die Leistung in Intelligenztests beeinflussen. Zudem werden differentielle Effekte beleuchtet. Der Beschulungseffekt ist für akademische Ausbildungsgänge ausgeprägter als für nicht-akademische und zeigt sich in verschiedenen Intelligenzfacetten und Altersgruppen, wobei er für jüngere Kinder am stärksten zu sein scheint. Die Beschulungsdauer ist mit Alterseffekten auf die Intelligenz konfundiert, und verschiedene Beschulungszweige bringen das Problem eines selektiven Intakes von Schülern mit sich. Daher stellt der vorliegende Beitrag außerdem Untersuchungs-Designs vor, mit deren Hilfe diese Probleme gelöst werden konnten. Abschließend wird resümiert, dass der Beschulungseffekt kein Artefakt darstellt, sondern die Folge einer „echten" Intelligenzsteigerung ist.

Schlüsselwörter: Schulbesuchsdauer, Effekte der Beschulung, allgemeine vs. spezifische Fähigkeiten, intellektuelle Entwicklung, Qualität der Beschulung

Introduction

While writing his famous line in one of the *epistulae morales*, Seneca lamented to his friend Lucilius about the lack of practical focus provided by the Roman schools of philosophy. Over the last 25 years, schools, especially in Germany, have faced similar accusations that they do not sufficiently orient on practical issues. One criticism, for example, was that they do not prepare students sufficiently for the world of employment, and that students accumulate inert knowledge in school, which they cannot use in their daily lives. But does schooling really produce only dull knowledge?

At their core, schools are tasked with teaching students certain academic and social skillsets, and supporting each student's personaldevelopment, all of which are prescribed within curricula and intentionally addressed during instruction. However, although not explicitly intended, schooling might go far beyond this. Children and adolescents undergo considerable growth in their intelligence, that is, in their "ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought" (Neisser et al., 1996, p. 77). From the beginning, a major focus guiding intelligence research, has been to identify what factors drive a child's intellectual development. Many explanations have been proposed, for example biological maturation,

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nutrition, or parental-guided intellectual stimulation (see Rost, 2013, for review). Interestingly, however, intellectual growth becomes especially sharp as children enter school age (e. g., Rindermann, 2011). Therefore, it remains a central question whether intellectual development might also (or even mainly) be due to schooling, especially given that teaching concepts such as "how to understand complex ideas", "how to adapt to the environment", "how to learn from experience", and "how to reason and take thought" are neither direct themes that can be found in school curricula, nor the intended reason behind such instruction.

In this review, we will discuss evidence suggesting that both the amount and the quality of schooling do indeed foster intelligence. Furthermore, we will show that schooling is the main driving factor behind intellectual development in school age children. We will also see that this schooling effect arises not only for school-related cognitive abilities such as general knowledge or verbal abilities, but also for more general and abstract intelligence facets such as reasoning. We will also discuss possible differential effects of schooling according to students' ages and levels of ability. Finally, we will outline that the schooling effect on intelligence is not an artificial improvement of intelligence test performance, but primarily due to "real" intellectual growth.

Duration of School Attendance and Intelligence

For many years, it has been known that there is a considerable association between the duration of school attendance and students' intelligence, ranging from $r \approx .50$ to $r \approx .60$ (Neisser et al., 1996; Rost, 2013). As the experienced empiricist will instantly remark, this association does not, of course, prove the effects of schooling on intelligence. It might well be possible that students who are already more intelligent stay longer in school, or that additional variables, such as parents' socioeconomic status, influence both the duration of school attendance and intellectual development, causing a spurious correlation between them. In his seminal review, however, Stephen J. Ceci discussed some evidence that schooling might indeed influence intellectual development (Ceci, 1991). For example, children's IQs slightly, but reliably, decreased during summer holidays. Similarly, leaving school early was associated with lower intelligence even after controlling for baseline intelligence, socio-economic status, and school performance. Based on these findings, he suggested that every year of school missed might cause a loss of IQ points.

However, rigorous testing of this hypothesis is challenging because duration of school attendance is but one of many other factors impacting intellectual growth. These factors comprise, for example, neuronal maturation and the accumulated amount of intellectual stimulation outside of school. All of these factors are indexed by chronological age and are therefore usually subsumed under the age effect. Unfortunately, the duration of school attendance is also indexed by chronological age: The longer students have attended school, the older they are; the older the students are, in turn, the more developed is their brain, and the more intellectual stimulation they have received outside school, etc. Therefore, the decisive question becomes how one can isolate a possible schooling effect from the age effect. In Excursus 1, we present sophisticated research designs by which this problem could be solved.

Excursus 1: Disentangling the Schooling Effect from the Age Effect

To isolate the schooling effect, some studies have taken advantage of cut-off dates for school enrollment. Within each cohort, there are children whose birthdays are close to the cut-off date. Therefore, some children will be enrolled relatively early (e. g. with 5;10 years), whereas some will be enrolled relatively late (e. g. with 6;10 years). After one year, the first group is at age 6;10, just like the latter group which is enrolling at that time. The first group, however, has already received one year of schooling. Thus, comparing their intelligence test scores provides an estimate for the effect of one year of schooling on intellectual development. However, whether a child is enrolled early or late is not independent from his or her cognitive abilities. Smart children will have a higher chance to enroll early. Thus, the first group might be pre-selected based on higher intelligence, whereas the latter group might be pre-selected based on lower intelligence. Consequently, direct comparisons between both groups might lead to an overestimation of the schooling effect. Therefore, findings from the cut-off design can only be interpreted if both groups have displayed equal intelligence test scores at the time point when the children from the first group were enrolled.

To overcome this problem, the regression discontinuity design was applied (RDD; Cahan & Cohen, 1989) (see Figure 1). In the RDD, students from at least two consecutive grades (e. g. grades 1 and 2) are examined. In the first step, a regression analysis within each grade is con-

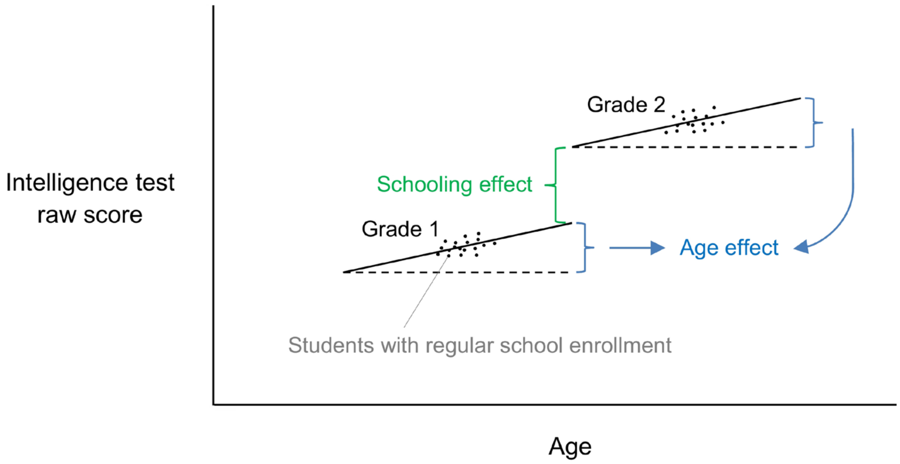

Fig. 1: Rationale of the regression discontinuity design to separate the schooling effect from the age effect on intelligence test scores

ducted. Within grades, the duration of school attendance will be constant, but the students' ages will vary by at least several months up to one year (see above). Therefore, predicting the intelligence test score from age will indicate the age effect on intelligence. Importantly, students who have entered school earlier or later and children whose birthdays fall into a certain range around the cut-off date for school enrollment are excluded from the analyses. In the second step, the intelligence test score of a relatively old student in the lower grade and of a relatively young student in the consecutive grade (having the same age as the old student from the lower grade) are extrapolated (i. e. estimated on the basis of the age effect obtained from the regression analysis based only on the classmates with regular school enrollment). Thus, the chronological ages of both "imaginary" students are the same, but the student from the consecutive grade has received one year more schooling than the student from the lower grade. Therefore, the difference between both students' extrapolated intelligence test scores indicates the schooling effect on intelligence.

Another approach is to examine students of the same cohort with slightly differing ages in intelligence assessments spread across one school year (Cliffordson & Gustafsson, 2008; Rost & Wild, 1995). In this design, some students are the same age, but differ slightly in their duration of school attendance (some are tested early and some are tested late in the school year). Intelligence differences then indicate the schooling effect of the respective time interval. Meanwhile other students differing slightly in their ages are tested at the same time point of the school year. Intelligence differences here would then indicate the effect of the respective age difference. In this way, very fine-grained statements can be made about the effects of, say, one month of schooling or aging on intelligence test performance.

Studies deconvoluting the schooling from the age effect revealed that every year of schooling imparts a considerable effect on intellectual development. Most studies found that one year of schooling causes an increase of about two to four IQ points (e. g., Brinch & Galloway, 2012; Cliffordson & Gustafsson, 2008). However, the magnitude of this effect is variable; prior studies found gains of about six to eight IQ points per year (e. g., Merz et al., 1985; Stelzl et al., 1995). In a review on intellectual growth in childhood and youth, the mean schooling effect was estimated at 5.6 IQ points per year (Rindermann, 2011).

Importantly, this effect is not limited to specific cognitive abilities. One might assume that the schooling effect arises only for school-related cognitive abilities, for example crystallized intelligence (i. e. knowledge and experiences acquired during socialization and, therefore, taught at school). However, studies have found that schooling impacts not only crystallized, but also fluid intelligence (i. e. the ability to reason logically and to solve complex problems without prior knowledge). Most studies find the effect to be roughly comparable across different intellectual abilities (e. g., Cliffordson & Gustafsson, 2008; Merz et al., 1985). For example, in a study with 10-year-olds, gains were 5.9 and 8.6 IQ points (depending on the measure) for verbal abilities and 7.6 IQ points for fluid intelligence (Stelzl et al., 1995). Whereas there are also studies finding larger effects on verbal than on fluid abilities, fluid abilities were still affected to large extent (e. g., Cahan & Cohen, 1989). Thus, the schooling effect is not limited to school-related abilities, but also refers to intellectual abilities not directly related to a curriculum.

Although magnitudes varied somewhat between studies and instruments, the schooling effect was always found to be markedly larger than the age effect. Some studies found the schooling effect to be about twice as large as the age effect (e. g. Cahan & Cohen, 1989). Furthermore, a majority of studies even found the age effect to be close to zero (Cliffordson & Gustafsson, 2008; Rost & Wild, 1995). According to these findings, intellectual growth in school-aged children seems to be mainly or even completely due to schooling. For example, in one study (Merz et al., 1985), the authors compared the estimated effect of one year of schooling with the overall IQ gain in one year, which they obtained from norm tables of the intelligence tests they had administered. For crystallized abilities, the schooling effect made up about 75 % of the overall development. By contrast, for fluid intelligence, 100 % of the overall development was due to schooling. Findings such as these are remarkable, because for a long time it was assumed that fluid intelligence is determined by biological factors and only marginally affected by the environment (Cattell, 1987). However, the schooling effects found on fluid intelligence have falsified this famous hypothesis.

But is the schooling effect the same for all individuals? For example, given the greater plasticity of younger children's brains, one might predict differential effects on IQ depending on students' ages. Indeed, the effect might be larger for younger children than for adolescents, as studies with elementary school children tend to find larger effects than studies with adolescents or young adults. For example, some studies with elementary school children found effects of about six to eight IQ points (Merz et al., 1985; Stelzl et al., 1995), whereas studies focusing on young adults (e. g. 18- or 19-year-olds) found effects of about three to four IQ points (Brinch & Galloway; Cliffordson & Gustafsson, 2008). However, this pattern is not consistent throughout, given that in other studies, the schooling effect was also about four IQ points for elementary children (Rost & Wild, 1995). Ultimately, a general trend remains elusive as long as there is no study comparing children from a range of different grades in the same schools using the same intelligence test. The same is true for other potential moderators, for example students' ability level. Given that the ability gap between individuals with higher intelligence and individuals with lower intelligence becomes larger as individuals develop (Matthew effect; e. g., Rindermann, 2011), one might assume larger schooling effects for smarter students. However, as of yet this has not been investigated. Taken together, it seems likely that there are systematic moderators underlying the variability observed in schooling effect sizes across these relevant investigations. However, to date, relatively little is known about them.

Quality of Schooling and Intelligence

Another focus of intelligence research centers on the impact that the quality of schooling has on intelligence. It might well be that not only the amount of schooling, but also its quality, fosters intellectual development. While this hypothesis has been comparatively less investigated, some results from the above-mentioned studies have already pointed to an effect of schooling quality. For example, it was found that different school tracks (e. g. technology, social science, economics) were differentially related to intelligence (Cliffordson & Gustafsson, 2008). However, this study did not control for possible differences in baseline intelligence across the tracks studied. In another study, baseline intelligence was controlled for, and differential track effects appeared nevertheless: Higher tracks produced larger IQ gains relative to lower tracks (Härnqvist, 1968). A more recent study took advantage of the tracked secondary school system in Germany (Becker et al., 2012). The authors investigated seventh graders from Gymnasiums and three lower-track school types (Sekundarschule, Realschule, Hauptschule) and retested them three years later. To establish comparability between the students from the Gymnasiums and the students from the other school types, they matched the Gymnasium students and the other students on a variety of variables (e. g. baseline intelligence, age, gender, social background, school performance). Subsequently, they inspected intellectual growth progress between both groups until tenth grade. Depending on the matching method employed, intellectual growth of students attending the Gymnasium was 23 to 31 % higher than for students attending the lower tracks. Recently, another investigation (Guill et al., 2017) extended on the Becker et al. study, drawing on a larger, more heterogeneous sample tracked from fifth to ninth grade, and using an additional school type (comprehensive school) for comparison. Although the effect size was somewhat smaller than in the previous study, comparable results were found: Students from Gymnasiums showed greater intellectual growth than students from non-academic tracks. Students from the Gymnasiums also showed somewhat greater growth than students attending the comprehensive school. Howeever, the latter effect was smaller than the first one, which could be expected given that comprehensive schools are at an intermediate academic level between Gymnasiums and non-academic tracks.

Taken together, these studies suggest that not only quantity, but also the quality of schooling impact intelligence. However, it remains an open question on exactly which instructional factors contribute to intellectual development. It might be that curricular content, teacher qualification, and instructional quality (e. g. cognitive activation, individualized support) are decisive factors. Class composition might also play a role, influencing student interactions and instructional quality through the amount of effective teaching time (Guill et al., 2017; Rindermann, 2007). Future studies should direct attention toward identifying specific factors underlying the effect of schooling quality on intelligence.

"Real" Intellectual Growth or Artificial Increase in Test Performance?

As the evidence shows, both quantity and quality of schooling improve intelligence test scores. However, a decisive question is whether this improvement is due to a "real" enhancement of intelligence or whether it is artificial. Some researchers have speculated that schooling fosters specific abilities that simply help the individual complete an intelligence test (Ceci, 1991; Neisser et al., 1996; Van de Vijver & Brouwers, 2009). For instance, schooling might improve students' self-regulation: Schooling might teach students adequate working behavior and working strategies, and students might also become more test-experienced. Higher scores on an intelligence test could therefore be achieved without a "real" enhancement of intelligence. In addition, schooling fosters specific abilities such as reading skills, mathematical skills, or general knowledge (e. g. Bisanz et al., 1995; Cunningham & Carroll, 2011). All of these abilities might be beneficial for successfully completing an intelligence test without a "real" increase in intelligence.

Conversely, there are also studies indicating that schooling impacts more general cognitive abilities that are context-free and not tied to a curriculum, for example conditional reasoning (Artman et al., 2006; Cahan & Artman, 1997; see also Baker et al., 2012). Relatively few studies have examined explicitly which of both hypotheses (artificial versus "real" increase of intelligence test scores) is most consistent with the observed data. Using structural equation modeling with longitudinal data from eleven-year-olds who had been retested at age seventy, Ritchie et al. examined whether development in general intelligence from age eleven to seventy would mediate the effect of years of education on specific cognitive abilities (Ritchie et al., 2015). Three models (full mediation, partial mediation, no mediation) were tested, whereupon the no mediation by general intelligence model best described the observed data. This finding suggests that schooling impacts specific abilities, but not general intelligence. However, the interval between the ages of eleven and seventy is a very long time span. It is possible that during this time, environmental or biological factors might have exerted their influences such that any possible effects of schooling on general intelligence might have dissipated.

Therefore, in one of our own studies (Bergold et al., 2017), we took advantage of the German G8 school reform to investigate the nature of the schooling effect on intelligence test scores at younger ages in two different samples of G8 and G9 students. With the G8 reform, the duration of school attendance had been shortened by one year. However, at the same time both the curriculum contents and the number of lessons were preserved. Therefore, if the impact of schooling on intelligence test scores was completely due to specific, curriculum-dependent abilities, no differences in intelligence test scores between the G8 and G9 students should have emerged because both groups had completed the same curriculum in the same number of lessons. It is worth noting that additional studies have been reported that utilize school reforms as "natural" quasi-experimental treatments (e. g. Brinch & Galloway, 2012). However, changes in those school reforms included *both* the number of years of education as well as modifications to the curricula. Therefore, those studies could not investigate whether the schooling effect is due to fostering of curriculum-dependent skills or due to fostering of more general, curriculum-independent cognitive abilities. Both G8 and G9 students from Sample 1 completed the Berlin Intelligence Structure Test (BIS; Jäger et al., 1997); G8 and G9 students from Sample 2 completed the Intelligence-Structure-Test 2000 R (IST 2000 R; Liepmann et al., 2007). Outlined further in Excursus 2 are details about the principle of intelligence testing with both the BIS and the IST 2000 R given as examples.

Excursus 2: How to Measure Intelligence

An intelligence test is grounded on an established intelligence model that defines and structures cognitive abilities. The items are deduced from the intelligence model, so that their content would represent the cognitive ability to be measured as well as possible. The problems presented in the items are usually clearly defined and the items most often have a multiple-choice format. Depending on the intelligence facet to be measured, items might involve different cognitive operations and contain verbal, numerical, or figural material. For example, tests measuring fluid intelligence will require the test taker to

Example 1: Verbal similarities

Find out the two words which have something in common.
(a) coffee (b) house (c) car (d) hill (e) tea (f) bread

(correct answer: a and e)

Example 2: Number series

The number series presented below follow a certain mathematical rule. Find out the rule and write down the next number.
1 3 5 7 9 ?

(correct answer: 11)

Example 3: Figural analogies

Three pictures are given. There is a relation between the first picture at the left and the second picture at the right side. There is a similar relation between the third picture below and one of the five alternatives (a), (b), (c), (d), and (e). Please find out the alternative for a correct relation.

(correct answer: d)

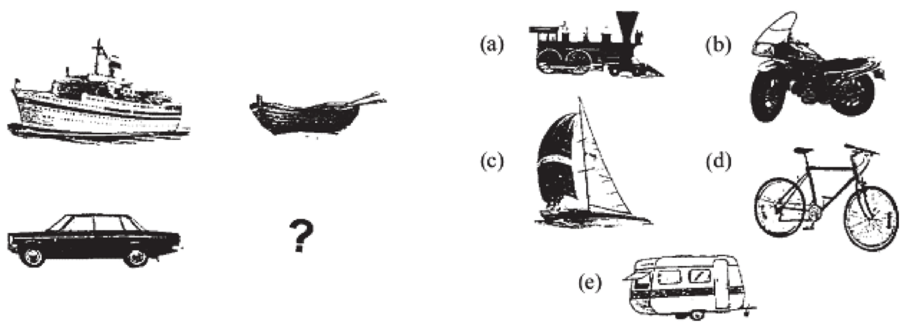

Fig. 2: Examples of (pseudo-)items measuring verbal (Example 1), numerical (Example 2), and figural (Example 3) reasoning ability (reprinted from Intelligence, Vol. 33, Schulze, Beauducel, & Brocke, Semantically meaningful and abstract figural reasoning in the context of fluid and crystallized intelligence, pp. 143–159, 2005, with permission from Elsevier)

solve logical problems illustrated by figural material. By contrast, tests measuring crystallized intelligence might assess the test taker's general knowledge and vocabulary. As another example, the BIS (which we used for Sample 1 in our study) distinguishes between four cognitive operations (operation speed, memory, creativity, and processing capacity) and the three types of cognitive contents (verbal, numerical, and figural). Their integral represents general intelligence. The basic module of the IST 2000 R (which we used for Sample 2) consists exclusively of tasks requiring logical thinking with verbal, numerical, or figural material, indicating verbal, numerical, and figural reasoning ability, respectively. The composite score indicates general reasoning ability which is closely linked to general intelligence. Figure 2 provides some item examples from the IST 2000 R (because of copyright protection, these examples are pseudo-items, reprinted from Schulze et al., 2005).

In both samples, the G9 students outperformed the G8 students in most of the intelligence facets assessed and, consequently, in general intelligence. Further, in a structural equation model (see Figure 3), the path from schooling (G8 vs. G9) to general intelligence was stronger than the paths from schooling to the more specific facets of intelligence. Although there were some limitations of the study, most notably being the missing control for baseline intelligence, the fact that similar results arose from both samples supports the conclusion that schooling causes a "real" enhancement of intelligence and not just an artificial improvement of test scores.

What exactly makes schooling a key factor for intellectual development remains an intriguing and open question. Intensive training programs for teaching children how to accurately reason have shown transfer effects to fluid intelligence (Christoforides et al., 2016; Klauer et al., 2002). In principle, schooling can be seen as a very intensive and protracted version of such a training program. Schooling allows students to experience that their reasoning made in daily life might be wrong. The conflict demonstrated in school between invalid daily life conclusions and valid conclusions might lead to cognitive accommodation (see e. g., Artman et al., 2006; Cahan & Artman, 1997). During their entire school career, students are confronted with cognitively challenging tasks in many different disci-

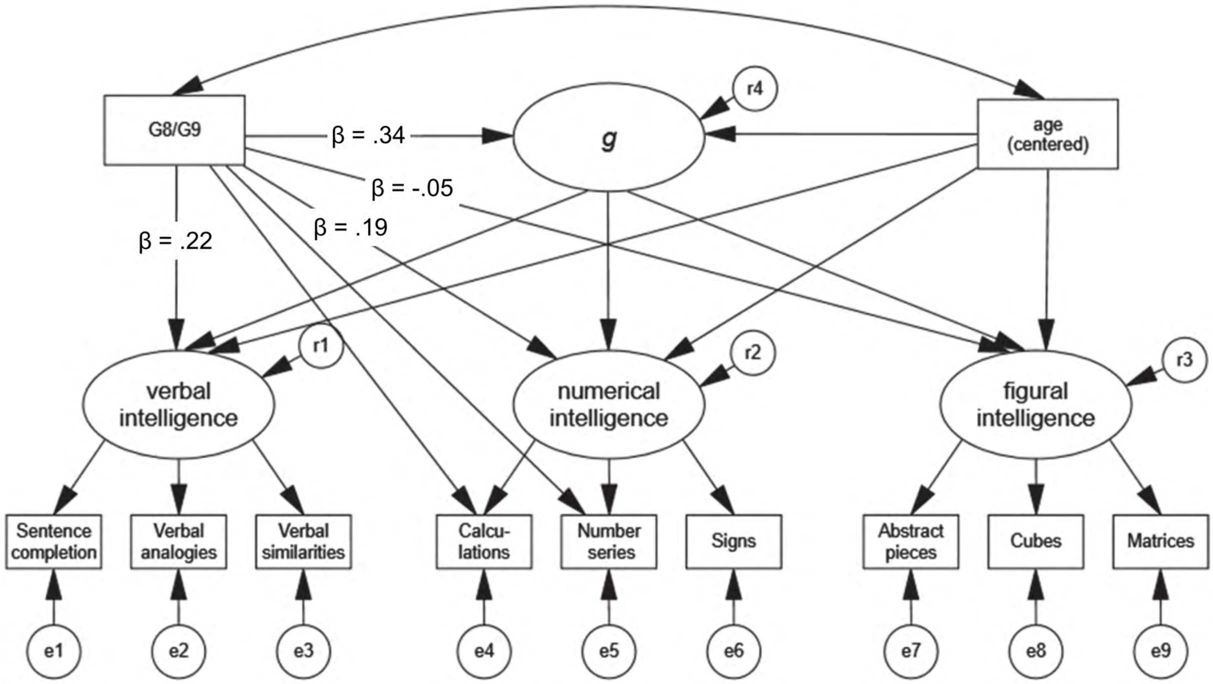

Fig. 3: Structural equation model of the influence of G8/G9 schooling on intellectual abilities (reprinted from Cognitive Development, Vol. 44, Bergold, Wirthwein, Rost, & Steinmayr, What happens if the same curriculum is taught in five instead of six years? A quasi-experimental investigation of the effect of schooling on intelligence, Study B, pp. 98–109, 2017, with permission from Elsevier)

plines, and they spend a great deal of time in elaborated cognitive processes. It is possible that the process of thinking (which is first bound to a concrete context presented in the lessons) separates over the years step by step from the problem context and transfers to more abstract levels, all of which might be underpinned by brain development. Accordingly, neuroscience research has found that mental activities typical for school (e. g. solving calculation tasks) activate neural substrates which are also responsible for reasoning, and that literacy probably changes brain structures (e. g. Baker et al., 2015; Carreiras et al., 2009). Furthermore, as was shown by means of the cut-off design (see Excursus 1), first graders showed a greater increase in activation of the right posterior parietal cortex than kindergarten children of the same age, underscoring their greater improvement in executive functioning (Brod et al., 2017). Therefore, continued instruction might serve as fruitful stimulation of brain development. It seems that through many years of instruction, children "learn to think." In summary, schooling is a very powerful device to foster individuals' intelligence. Thus, it should be in the best interests of a nation's wealth and prosperity to invest as much as possible in high-quality education of children as young as possible.

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