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Laptop usage affects abstract reasoning of children in the developing world

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ABSTRACT

There is a rising trend to provide low-cost laptops to children in developing countries. Notwithstanding strong claims about the educational effectiveness of these programs, there is very little systematic evidence. Given the level of modernization and the teacher-led learning environment in developing countries, the usage of laptops in such contexts may affect children in ways that are quite different to how they would affect children in developed countries. A field experiment was conducted to compare abstract reasoning of Ethiopian children equipped with a laptop ($n = 203$) with a matched control group ($n = 210$) after 6 months of usage. Children with a laptop had significantly higher scores on finding analogies and categories. Effects were significant among children in grade 6 and 7, but not in grade 5. Different laptop activities may boost children's abstract reasoning. Theoretical and practical implications and the implemention of laptops in developing countries are discussed.

1. Introduction

Laptop programs for students recently have been proliferating in developing countries. Different non-profit and for-profit manufacturers have developed low-cost laptops, often for applications in the developing world. Prominent examples are the XO laptop that was developed by "One Laptop Per Child" (OLPC, a spinoff of the Massachusetts Institute of Technology Media Lab) and the Intel Classmate personal computer. The idea behind these low-cost laptops is that they may improve students' learning outcomes and educational prospects. OLPC, an American-based non-profit organization, for example, has attracted an estimated initial investment of at least $255 million (excluding costs of deployment, power, and maintenance) to provide laptops for children in developing countries. Among the biggest takers are countries such as Peru (580,000 laptops), Uruguay (420,000 laptops), and Rwanda (110,000 laptops).[1] Ethiopia was the first African country to receive 5900 laptops from the OLPC initiative in 2008. The current research set out to test the effects of one such laptop program for the cognitive development of children in Ethiopia.

Surprisingly, the empirical evidence of the effectiveness of these programs is somewhat piecemeal. What research there is, has mainly focused on effects in developed countries. Furthermore, the outcomes of these programs appear to be somewhat inconsistent (for overviews see Penuel, 2006; Zucker & Light, 2009). Given the very different learning environment in developing countries and the lack of computer experience, the usage of laptops in such contexts is likely to affect children in ways that are quite different to how they would affect children in developed countries. This paper reports results of what is, to our knowledge, the first publicly available quantitative study to systematically investigate the effects of a laptop program (i.e. OLPC) on abstract reasoning skills of children in a developing country.

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[1] These and following figures are based on deployment statistics of OLPC. Available at http://wiki.laptop.org/go/Deployments/, updated at time of writing until January 2011.

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1.1. Computer and learning experience in developing countries

For people in developed countries, it may be hard to imagine what the access to a laptop means to children in developing countries. Computers are a thoroughly integrated part of daily life in wealthy countries. To illustrate, among 1000 people in the US, 805 people had a personal computer and 735 had access to the internet in 2007 (Worldbank, 2009). In Ethiopia, where this research was conducted, estimates are that only 7 out of 1000 owned a PC and only 4 had access to the internet (Worldbank, 2009). Thus, providing children with laptops in a country like Ethiopia is likely to affect children's learning experience quite differently to how they would affect it in developed countries. But what these impacts consist of is hard to predict, based on current research evidence.

1.2. Educational outcomes of ICTs

Previous research examining learning outcomes of programs providing computers or laptops to children is somewhat limited. To begin with, most of these studies were conducted in developed countries, where schooling is markedly different and where many children have access to computers at home. A second concern is the heterogeneity of the research: Studies not only differ in their methodological approach but also in the nature and quality of the research design. A recent review article of 30 studies on laptop programs for students noted that only *four* studies used rigorous quasi-experimental designs (Penuel, 2006). Similarly, Nugroho and Lonsdale (2010) concluded in a recent literature review of the evaluation of OLPC programs that such research often relied on anecdotal evidence, and that evaluations are mainly related to training needs and technical matters rather than educational outcomes. In addition, Nugroho and Lonsdale (2010) noted that evaluations are often not conducted by externals and did not employ rigorous designs. Likewise, a recent review on the effectiveness of ICT usage in education in developing countries noted that "the impact of ICT use on student achievement remains difficult to measure and open to much reasonable debate" (Trucano, 2005, p. 5). Finally, different technologies and activities afforded by the laptops and different implementation approaches make it hard to compare results across studies.

With these caveats in mind, systematic (quasi-)experimental studies of laptop programs in schools found evidence for four possible learning-related effects. First, several studies in wealthy countries (Bebell & Kay, 2010; Schaumburg & Issing, 2002; Trimmel & Bachmann, 2004) and an evaluation study of the World Links program conducted in thirteen developing countries (Kozma, McGhee, Quellmalz, & Zalles, 2004) reported that laptop usage increases students' *engagement in school*. Second, a widely reported outcome is that using computers in schools increases *technology skills* of students in both wealthy (Schaumburg & Issing, 2002; Shapley, Sheehan, Maloney, & Caranikas-Walker, 2009; Trimmel & Bachmann, 2004) and developing countries (Kozma et al., 2004; preliminary results of the Inter-American Development Bank, 2010). Third, a few studies found evidence for some positive effects on *students' writing skills* in wealthy countries such as better structuring of texts or greater length (Goldberg, Russell, & Cook, 2003; Gulek & Demirtas, 2005; Light, McDermott, & Honey, 2002; Schaumburg & Issing, 2002; Suhr, Hernandez, Grimes, & Warschauer, 2010). Finally, only one study, a 4-year longitudinal study in Texas comparing more than 20 experimental schools to control schools found significant improvements on students' test scores in *mathematics*, but only in grade 7 and 8 (Shapley et al., 2009). Whether in-class laptops aid or hinder learning is an ongoing debate (e.g., Fried, 2008; Wurst, Smarkola, & Gaffney, 2008).

In sum, prior research (conducted mostly in developed countries) suggests that using laptops could have positive effects on school engagement and technological skills. Research in developing countries has corroborated these effects (Kozma et al., 2004). Only in developed countries, however, have some studies reported effects on concrete learning outcomes such as writing skills and mathematics. But overall, it should also be noted that the evidence for these programs' educational effectiveness is quite limited—especially if one takes into account the number of studies which did not find any significant effects (e.g., Barrera-Osorio & Linden, 2009; Penuel, 2006). Nevertheless, it seems too soon to conclude that the educational effects of laptops are negligible. It is quite possible that laptop usage does not directly affect the skills examined in the school curriculum – such as writing skills and mathematics – but rather influences more deep-seated cognitive performance fundamental for learning. Strikingly, the effects of laptop usage on such fundamental cognitive performance have not been systematically examined in developing countries so far. This field experiment set out to fill this gap by systematically comparing children who were using a laptop with a control group in a developing country.

1.3. Cognitive effects of low-cost laptops in context

Research in developmental psychology compared cognitive skills of children across four different countries which differed in their level of modernization (Gauvain & Munroe, 2009) and found that children in less modernized countries showed weaker cognitive performance. In line with this research, we suggest that there are several reasons why the primary impact of laptops on children in developing countries is going to be on cognitive performance rather than school performance. To these children, the laptop is a source of new experiences in an environment where, normally, their exposure to new information is severely restricted. In most developing countries, schooling tends to be teacher-led, and focused on acquisition of concrete skills and the class-wide memorization of facts (cf. Penuel, 2006) with for example an average of 73 students in class in Ethiopia (UIS, 2008). Furthermore, there is a widespread lack of textbooks and inadequate access to extracurricular learning materials. In this context, students lack the opportunity to independently encounter substantial amounts of new knowledge.

To children in the developing world, therefore, a laptop represents an information-rich novelty, which does not immediately compare to any other prior experience. The software that OLPC provided in Ethiopia, enabled students to read their schoolbooks on the laptop, draw free-form images, browse an offline database of Wikipedia articles and a picture gallery, play memory games, or make pictures and videos, make calculations, use a text editing application, chat with other laptops within 10 m or explore applications to compose music (for an overview see Table A1).[2] Although the laptops were not connected to the internet at the time of the study, the activities on the laptop

[2] All programs are described on the OLPC website. Available at http://www.laptop.org/en/laptop/software/activities.shtml. Accessed on May 30, 2011.

provided a spectrum of tasks and knowledge that was very different from everything the children had hitherto encountered or experienced, and most of these were only indirectly related to school.

Learning to operate on this new machine is, in itself, a learning experience that is likely to have a cognitive impact. Prior research has shown that training specific skills (i.e. training on working memory) can transfer to more general abilities (i.e. fluid intelligence; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). Laptops in developing countries train various skills and make novel demands on children's abstract reasoning abilities: Children are constantly abstracting from their existing understandings and seeking to apply it to this totally new environment. This ability to transfer and integrate knowledge is of central importance to human cognition (Gentner, 2003).

The laptop thus offers an entirely new environment for the development of specific cognitive skills. It is a multimedia platform with verbal and visual information. In line with multimedia learning (Mayer, 1997) the learner engages in three basic cognitive processes: selecting, organizing and integrating verbal and visual information. To be able to engage in these three processes, we expect that children will need to make use of familiar situations and environments to make inferences about the new unfamiliar environment and processes inside the laptop. More precisely, when students start exploring the activities provided by the laptop they will use their reasoning abilities to learn more about the similarities and differences between the activities. This connection and integration of the known and the unknown relies on two distinct cognitive capacities: *Reasoning by analogy* and the application or development of *categories* or schemas, both of which (a) integrate the laptop into existing knowledge structures, and (b) uncover regularities and structures among the different laptop activities (e.g., Gentner, 2003; Gentner & Holyoak, 1997).

The development of these reasoning abilities is fundamental to learning. Very young children already make use of analogies as a primary tool for acquiring understanding of their environment (Newcombe, 2002; Piaget, Montangero, & Billeter, 1977). Perceived similarities enable one to organize objects and events into familiar categories – cows and goats, parents and friends (Gentner & Gentner, 1983; Holyoak & Thagard, 1995). These categories are formed through the mechanism of analogy – the process of understanding a novel situation in terms of one that is already familiar. The familiar situation (i.e. base analog) provides a kind of model for making inferences about the unfamiliar situation (i.e. target analog). In the course of reasoning by analogy, the novel target comes to be seen as 'the same kind of thing' as the familiar analog. To children in developing countries, the laptop would appear to offer a vast range of opportunities for reasoning by analogy: this might be the prime way to understand the operations of the laptop.

Somewhat related to analogies, the ability to categorize enables children to uncover regularities and structures in the world around them. The analogy between two specific situations may provide the seed for learning a more general category that encompasses both. This enhances their capacity to process and understand large amounts of information by discerning key similarities within one category, differences between categories, and relationships between categories (e.g., Smith & Medin, 1981). Again, laptops should require children to expand their ability for reasoning by category. These abstract reasoning abilities are an essential component in a wide range of cognitive processes, including problem solving, constructing explanations, and building arguments (e.g., Gentner, 2003; Newcombe, 2002) and are related to educational success (Neisser et al., 1996; Rohde & Thompson, 2007).

In sum, we expect that laptop use will affect more fundamental cognitive performance of children in developing countries than so far considered in research. Training new skills by engaging in the laptop activities should result in increased abstract reasoning ability. Concretely, we expect that children who were using a laptop for a sustained period will perform better in abstract reasoning by analogy and category compared to a control group.

1.4. The current study

In this study we investigated the impact of laptop usage among children in Ethiopia. After the laptop deployment in Ethiopia, children were first guided in their learning process by their teachers (i.e. guided discovery; Mayer, 2004). Students learned how to discover the activities provided by the laptop. They became familiar with several activities such as browsing their schoolbooks, using the writing and calculator activity, and playing games. After they had received some guidance to become familiar with this new multimedia learning tool, they started exploring the activities themselves by using reasoning abilities to learn more about the laptop activities. We hypothesized that children who were using laptops in this way should, for reasons outlined in the previous section, outperform children without laptops on abstract reasoning tests of forming analogies and categorizing objects 6 months after deployment of the laptops. Furthermore, we expected to replicate age-related improvement on the reasoning measures (e.g., Bjorklund, 2005). We first examined the actual laptop usage to learn more about how laptops are implemented in students' life in Ethiopia and which activities students engage in. Additionally, we tested whether laptop usage would impact on school performance and school engagement as studied in prior research in developed countries.

2. Method

2.1. Project description

4375 laptops of the One Laptop Per Child (OLPC) initiative were available for distribution in Ethiopia. For logistical and educational reasons, laptops were distributed to entire schools. Schools thus participated in the deployment of laptops and children were also allowed to take their laptops home. Participating schools were selected by the Ethiopian organization responsible for deployment. They were located in three regions across the country, based on four criteria: social status of the students had to be about average for the region, school/classroom size had to be equivalent to an average Ethiopian school, school equipment had to be of a suitable standard (e.g., with electric power and desks for the laptops), and accessibility of the school for support and research had to be good. Finally, staff had to be willing to participate in the scheme. Out of all potentially suitable schools, 11 were shortlisted for a visit, and four were selected because they most closely matched criteria (see Kocsev, Hansen, Hollow, & Pischetola, 2009). In three of these schools all children received a laptop. In the fourth school, which was quite large, not enough laptops were available for all children. In this school, classes for deployment were randomly selected (two in each grade) and the school was promised that all remaining classes would receive a laptop with the next deployment.

Prior to deployment of the laptops, parents and officials were informed about the scheme. Furthermore, teachers in participating schools received an own laptop and extensive professional development training to familiarize them with equipment and software, and to stimulate the use of the laptops and digital schoolbooks in class. The professional development was offered by two organizations [Gesellschaft für Technische Zusammenarbeit (GTZ) and InWent]. All professional development programs were compulsory and were conducted in the schools, in the familiar setting of the teachers. The professional development programs were officially recognized as professional development measures by the local education authorities. The GTZ organized two different development programs given by local personnel in the local language spoken in the schools (i.e. Amharic, Oromifa, and Tigrigna). Teachers attended both programs. Each program lasted 40 h. The programs focused on teaching software and hardware knowledge as well as integrating particular applications (mainly the writing activity and schoolbooks) into the standard teaching curricula. In addition, Inwent offered a professional development program to stimulate laptop usage in class to adopt new didactical approaches to stimulate more interactivity in class given by English-speaking international personnel. The program lasted 20 h. In total, 320 teachers participated in the programs. In the school in which only half of the classes were equipped with laptops, *all* teachers (including the ones whose students did not receive laptops) participated in these programs.

Students were guided by their teachers in their first exploration of the laptops (i.e. guided discovery; Mayer, 2004) so that they became familiar with some activities provided by the laptop. Because of the lacking infrastructure, laptops could not be connected to the Internet. Students were allowed to take laptops home at all times.

2.2. Sample and design

As mentioned, in one school half the classes received a laptop, the other half did not. In three other experimental schools, all children received a laptop. They were compared with matched control schools in the same region, selected based on the same criteria as well as matching student demographics. The final sample thus consisted of three experimental schools in which all children were equipped with laptops, three matched control schools and one school in which half the classes were equipped with laptops and half were not. This provided a quasi-experimental setting in which to study the effects of laptops on child development.

Within all schools a stratified random sample was taken of classes in grades 5, 6 and 7. Of the 413 participating children, 202 owned a laptop, 210 did not. Demographic characteristics such as age, gender, and religion of the two groups were equivalent. Children were aged 10–15 years old ($M = 11.95$, $SD = .91$) and 52.3% were girls (see also Table A2).

Six months after receiving the laptops, children were invited by native-language research assistants to participate in a study on child development in Ethiopia. All children consented, and were individually administered two subtests of a validated intelligence test (Tellegen & Laros, 2011) and filled in a questionnaire assessing their motivation to go to school. Students who had received a laptop were also asked to answer questions related to their actual laptop usage.

2.3. Measures

2.3.1. School performance

Students' grades were gathered at two time points: in the semester just before the deployment of laptops and at the end of the semester in which abstract reasoning was assessed (approximately 8 months later). Because some activities (e.g., Wikipedia) on the laptop were presented in English and prior research in developed countries found some learning benefits in writing and mathematics, we focused on grades in *English* and *mathematics* as well as the *overall grade*. In Ethiopia grades are given on a continuum from 0 to 100 with higher scores indicating better performance.

2.3.2. Abstract reasoning

In order to assess abstract reasoning abilities independent of reading ability and language differences between regions, we relied on the newest version of the Snijders-Oomen Non-verbal intelligence test SON-R 6-40 (Tellegen & Laros, 1993, 2005, 2011). The SON-R test has been validated and standardized cross-culturally (Tellegen & Laros, 2011). Children completed two subtests, one to measure reasoning by analogy and one to measure reasoning by categorization. The tests were administered one-on-one for each child in an adaptive test procedure without time pressure by trained indigenous assistants, who were blind to the hypotheses and did not know whether children owned a laptop or not. Instructions were given in the native language of the children (Tigrigna, Oromifa, or Amharic).

Each test consists of 3 example items and 3 series of 12 test items. In these tests, a principle of order must be derived from the test materials presented, and applied to new materials (Tellegen & Laros, 1993). Children could score a maximum of 36 points for each test. Each test page presented one item. Each subtest took on average 10 min to complete. Example items with instructions and explanation are depicted in Fig. A1 (analogies) and Fig. A2 (categories). Standard administration procedures were followed. Thus, children indicated the answer by pointing to one (analogies test) or two (categories test) of the pictures. When they made two errors in one series, the test administrator stopped the series and continued to the next series (in a total of 6). The analogies test was administered first.

2.3.3. School engagement

Children were asked to indicate the extent to which they were motivated to go to school (e.g., Deci & Ryan, 1985) by circling one of 5 "smileys" ranging from not at all (☹ = 1), a little bit (☹ = 2), average (😐 = 3), quite a lot (☺ = 4), and very much (☺ = 5). This scale has previously been used when studying children's social norms (e.g., Rutland, Cameron, Milne, & Mc George, 2005) and cultural values (Hansen, Postmes, van der Vinne, & van Thiel, in press).

2.3.4. Laptop usage

We further examined how students actually used their laptop to gain more insight in the specific context. We adopted several items used in previous research on computer usage in developing countries (e.g., Kozma et al., 2004). In a separately administered questionnaire, students who had received a laptop were asked to indicate how often they used their laptop in school, at home, and for learning purposes on four-point scales with 1 = 'never', 2 = 'a few times per month', 3 = 'multiple times per week', and 4 = 'every day'. The three items were collapsed into one reliable scale of *frequency of usage*, $\alpha = .70$. Furthermore, we asked students for the *place where they most frequently used their laptop*. They had to make a choice between in class, in school during break, at home, or outside their home. Finally, students were asked to indicate their *favorite activity* on the laptop. Based on a pre-test eight categories easy to understand for students were provided: chat, write, record, painting, memorize, calculator, game, and browse activity (see also Table A1).

3. Results

3.1. Laptop usage

We first examined how students actually used their laptop in their daily lives. In general, students indicated that they used their laptop on average multiple time per week ($M = 3.09$, $SD = .76$). Important to note is that in Ethiopia the majority of students can only recharge their laptops at school, and thus one might assume that school becomes the main location where laptops are used. Nevertheless, laptops were more frequently used at home ($M = 3.31$, $SD = .81$) than at school ($M = 2.88$, $SD = 1.07$), $t(183) = -5.62$, $p < .001$. Most interestingly, students indicated using their laptop during breaks at school (58%) and outside their parental home (28.7%), but less often inside their home (10.5%), and hardly ever in their classrooms (2.8%). Similar observations have been made by others monitoring the implementation in Ethiopia: laptops were hardly used in classes (Hollow, 2009). If teachers used the laptops in class they mainly used the schoolbooks available on the laptop.

Furthermore, students indicated that their favorite activity on the laptop was the writing activity (33.9%), followed by browsing schools books and offline Wikipedia pages (18.6%), the painting activity (9.6%), gaming activities (12.4%), the record activity (11.3%), memorize activity (4.0%), calculator (5.6%), and finally the chat activity (2.3%).

To conclude, laptops are hardly used for teaching purposes in class and are mainly used during break times at school and outside students' homes. Students carried out a variety of activities on the laptop, among which writing, reading and gaming appear to be most frequently engaged in.

3.2. School performance

Next, we tested whether there were systematic differences in school grades between control and experimental schools in the semester immediately preceding the laptop deployment. An analysis of variance revealed no significant differences between laptop and control schools in mean grades for English, $F(1, 319) = 1.74$, *ns*, mathematics, $F(1, 319) = .00$, *ns*, or overall grades, $F(1, 319) = .90$, *ns* (see Table A3). More importantly, we examined changes in school grades over time, in a 2 (lapto0p) × 3 (grade) × 2 (time: baseline vs. end of semester after laptop deployment) analysis. The crucial laptop by time interaction was not significant either for English, mathematics or overall grades, all Fs < 2.67, $p > .10$, *ns*. Thus, there were no systematic increases in student performance due to laptop use. The other interactions with laptop were also all non-significant, with the exception of two unexpected 3-way interactions on *mathematics*, $F(2, 319) = 15.33$, $p < .001$, and *overall grades*, $F(2, 319) = 7.92$, $p < .001$. Close inspection of the means shows this was caused by an unexpectedly sharp increase of mathematics grades and as a result also the overall grades among students in grade 5 in the *no laptop* control condition. Given the isolated nature of this effect (see also below) we attribute this effect to chance and conclude it is unlikely to have been caused by the experimental intervention.

3.3. Abstract reasoning

Two separate 2 (laptop vs. no laptop) × 3 (grade 5 vs. grade 6 vs. grade 7) analyses of variance on the *analogies* and *categories* tests were conducted. Children with laptops significantly outperformed children without laptops on both tests [analogies: $F(1, 407) = 16.37$, $p < .001$, $d = .31$; categories: $F(1, 407) = 11.29$, $p < .002$, $d = .30$]. Furthermore, both tests showed main effects of grade [analogies: $F(2, 407) = 23.00$, $p < .001$, $\eta^2 = .10$; categories: $F(2, 407) = 21.24$, $p < .001$, $\eta^2 = .09$] indicating that children in higher grades score higher than children in lower grades.

In addition, significant *laptop × grade* interactions were found [analogies: $F(2, 407) = 9.50$, $p < .001$, $\eta^2 = .04$; categories: $F(2, 407) = 3.69$, $p < .05$, $\eta^2 = .02$], indicating that the effect of laptop on abstract reasoning increased per grade, from non-significant effects in grade 5 (analogies: $d = .15$, *ns*; categories: $d = .00$, *ns*), to medium-sized effects in grade 6 (analogies: $d = .52$, $p < .001$; categories: $d = .47$, $p < .01$), and medium-to-large effect in grade 7 (analogies: $d = .88$, $p < .001$; categories: $d = .58$, $p < .05$) (see Table A3, Fig. A3).[3]

3.4. The impact of laptop usage and abstract reasoning

In a next step, we investigated whether laptop usage can explain the grade differences. Parallel to the abstract reasoning results, fewer children in grade 5 report using their laptop every day (21.4%) compared to children in grade 6 (56.6%) and grade 7 (80.4%). Moreover, the frequency of laptop usage was significantly related to higher abstract reasoning [analogies: $r(184) = .16$, $p = .03$; categories: $r(184) = .22$, $p = .003$]. We further tested whether students favored different activities, and whether this might explain the grade differences. By separating educational practice and the personal learning situation we can get a deeper understanding of the role of laptops during learning activities (Lindroth & Bergquist, 2010): The writing activity is most commonly used in educational practice in class (Kocsev et al., 2009), whereas games and consulting the offline Wikipedia are activities which students do independently of their teacher outside the classroom. Interestingly, among 5th graders, the writing activity was the most favored application (5th graders: 40.5%; 6th graders: 30.1%; 7th graders: 26.7%). Older students more often favored games and consulting the offline Wikipedia (5th graders 23%; 6th graders: 35.5%; 7th graders: 50%).

[3] Gender did not have an impact and was thus omitted in further analyses. Furthermore, to take the nested structure of the data (with individual students nested in classes and classes in schools) into account, we also ran multilevel analyses. Even when controlling for school-level and class-level effects, the main effect of the manipulation was still significant. For ease of understanding we decided to report analyses of variance.

In sum, the usage data seems to suggest that children in higher grades use their laptops more frequently, and prefer different and more diverse activities that are likely to stimulate problem-solving abilities to pursue their personal learning situation (e.g., Lindroth & Bergquist, 2010). This may potentially explain why the abstract reasoning abilities are more strongly affected by laptop usage the more advanced students are.

3.5. School engagement

Next, in line with earlier research we tested whether having a laptop increased students' school engagement. A 2 (Laptop: control vs. laptop) $\times$ 3 (Grade: 5th vs. 6th vs. 7th) ANOVA did not show any significant differences (all Fs $< .57$).

3.6. Professional development of the teachers

Finally, we exploratively examined an alternative explanation of the results that these effects might be driven by the additional professional development training provided to teachers of schools in which laptops were deployed. Were the effects reported above due to the laptops, or due to the teachers? In one school only half the classes had received a laptop. However, all teachers in this school received the same additional professional development aiming to instruct them in the usage of the laptop and its potential classroom applications as in the other schools. This may have increased teacher's motivation to teach students in general. In this school, we could therefore test whether the professional development was responsible for increases in students' abstract reasoning scores. Two separate 2 (Laptop: control vs. laptop) x 2 (Grade: 6th vs. 7th)[4] analyses of variance yielded significant differences [analogies: $F\,(1, 109) = 24.55$, $p < .002$, $\eta^2 = .18$; categories: $F\,(1, 109) = 22.33$, $p < .002$, $\eta^2 = .17$] suggesting that it was not the professional development course of the teachers that was responsible for performance improvements, but the laptop usage itself.

4. Discussion

To the best of our knowledge, this is the first systematic quasi-experimental study that examines the impact of laptop usage among children on abstract reasoning in a developing country with a control group. The present study focused on two different abstract reasoning abilities which may stimulate learning in a fundamental way. Results demonstrate that six months after deployment, Ethiopian children who were having laptops outperformed children without laptops on abstract reasoning tests of reasoning by analogy and categorization.

This research has replicated typical age-related patterns in children's abstract reasoning abilities (Bjorklund, 2005): Our data shows that laptops had effects on the performance of students in higher grades, but not on those in lower grades. Other studies report similar findings: computers in class were found to improve students' test scores in mathematics only for grades 7 and 8, not for younger children (Shapley et al., 2009). The present data suggests some reasons why these effects are stronger for higher graders: students in grade 6 and 7 appear to use the laptop more frequently than those in grade 5. Furthermore, older children used a more diverse range of activities. Many of the applications used by older children offered opportunities and tasks which were not ordinarily available to them in class or in their daily lives. Thus, they were exposed to a broader range of novel experiences, and this may have further boosted their performance on the abstract reasoning tests. In contrast, younger students used the laptop less, and used a smaller range of applications, focusing mainly on the writing activity which was used most frequently in class (guided by the teacher) and which is conceptually very similar to writing with pen and paper. The reasons for these different patterns of usage we can only speculate about: It is possible that younger students were simply not sufficiently developed and/or skilled to make full use of the laptop's diverse applications and explore them independently.

Literature suggests that abstract reasoning abilities are associated with a wide range of problem-solving abilities, mathematical skills, constructing explanations, building arguments and more generally benefit insight, understanding and creativity (e.g., De Lisi & Wolford, 2002; Gentner, 2003; Gentner & Holyoak, 1997; Newcombe, 2002). It is also considered to be an important factor in learning that is closely related to educational performance and success (Neisser et al., 1996; Rohde & Thompson, 2007). Indeed, abstract reasoning is a key part of many intelligence tests (for an overview see Carroll, 1993; Neisser et al., 1996). Our findings are the first sign that the introduction of laptops in developing countries may indeed improve abstract reasoning abilities of grade 6 and grade 7 students, six months after laptop deployment. Whether these abilities will translate to the above-mentioned abilities and more general outcomes such as improvements in school performance in the long run remains an empirical question.

We further tested the hypothesis that students who were given a laptop showed improved *performance in English and math* and were more *motivated to go to school*. In contrast to some earlier studies, mostly conducted in developed countries, we did not find any evidence of these effects. However, as mentioned in the introduction, the evidence for these effects in other studies has been quite limited (Nugroho & Lonsdale, 2010; Penuel, 2006; Zucker & Light, 2009), and so our study is one of several that fails to replicate these findings. Furthermore, considering the fact that laptops appear to be hardly used in class and are more frequently used during breaks and outside school, the absence of laptop effects on school-related outcomes and school engagement may not be surprising. Thus, the skills which are likely to be stimulated by the laptop activities need to be tested more directly in school assessments. Reasoning benefits *may* accrue if these laptops are more tightly integrated into the school curriculum and the assessments. For now the benefits were not found on learning outcomes such as grades.

Finally, we tested an alternative explanation for our findings, namely that teacher professional development may have influenced students' performance. But in one school with laptops and controls, all teachers were trained, and we still replicated the result that laptops benefited abstract reasoning. Thus, professional development was not responsible for improving students' performance, at least in this school.

[4] In this school there were no 5th graders who received a laptop.

4.1. Theoretical implications

The current research shows that Ethiopian children who were given a laptop improved their reasoning abilities. The effects appear to be quite large compared with the broader literature, which rather suggests that such programs have quite limited effects on children in the Western world (Penuel, 2006; Zucker & Light, 2009). The relatively strong effects[5] in grade 6 and 7 in the present study may be due to the context in which the current research was conducted: For Ethiopian children, the laptop is a dramatically different experience from everything they have hitherto encountered.

Furthermore, unlike most prior research, we assessed effects on abstract reasoning using a standardized non-verbal test. We found significant differences in grade 6 and 7. We argue that laptop usage improved this kind of reasoning because of the need to make analogies and categories that classify and order the novel activities and information offered by the laptop in relation to knowledge that was already familiar. This effect was most strong among older children, who used the laptop more intensively, and who explored a more diverse range of activities compared with younger children. The skills trained with the laptop activities enhanced children's ability to uncover regularities and structures in the world around them through analogies and categorization. Getting familiar with the laptop and its activities such as memory games, reading textbooks, searching for information, or creating paintings and video clips are likely to have improved both types of reasoning abilities. Our results seem to suggest that practicing these diverse activities stimulated different skills which transfer to abstract reasoning abilities (see also Jaeggi, Buschkuehl, Jonides, & Perrig 2008). Although some consider abstract reasoning to be a key aspect of intelligence (e.g., Carroll, 1993; Neisser et al., 1996), future research needs to investigate whether these reasoning abilities transfer to more general abilities and educational success in the long run.

At a more abstract level, our research adds to a broader literature examining the cognitive consequences of modernization and technology. First, our findings resonate with research that suggests that modernization in a more general sense could be related to improvements in abstract reasoning abilities (Gauvain & Munroe, 2009). Second, our results chime with the literature examining effects of video gaming and computer use on logical reasoning abilities through spatial cognition (De Lisi & Wolford, 2002; Feng, Spence, & Pratt, 2007; Terlecki & Newcombe, 2005). For instance, some forms of video gaming improved spatial attention and mental rotation abilities in adults (Feng et al., 2007) and computer game playing improved mental rotation abilities in children aged 8/9 (De Lisi & Wolford, 2002). The present research demonstrates something conceptually similar, although not specifically related to gaming: In the analogies test, children made some use of the properties of figures and their transformations in space in order to acquire answers for the test items. In the categorization task, however, children did something qualitatively different from spatial cognition. Here they identified the construct underlying a set of pictures and choose other pictures with the same construct or belonging to the same category. This test therefore assessed the capacity to attach meaning to an object's visual properties. Thus, students' use of laptops did more than improving spatial cognition: They enabled children to categorize their new knowledge.

4.2. Limitations and future research

A field experiment provides the opportunity to test theoretical assumptions in an applied context, and (in this case) to test a hypothesis that could not otherwise be examined. However, field research also raises methodological challenges. Principal among them is the risk that contextual variables may influence the results. In the present research, whether children had a laptop or not was naturally confounded with a host of factors we could not possibly control. The laptop may have exerted its effects due to the activities carried out on it, through the status it afforded, because the children were given a new toy and thus played more, or because of other unknown factors. We have tested and discussed a few alternative explanations based on our data. There are clear signs that laptop usage was instrumental in producing these effects, if only partially. The constraints of our field experiment do not permit us to know what other factors may have influenced the results as well.

In addition, future research is necessary to test whether the observed effects indeed translate to more general abilities and educational success in the long run. Research is also needed to test how much laptop usage is required for the achievement of performance improvements over time. The amount of usage is an important issue for further study because the amount could have important practical implications for those responsible for laptop programs for students in the developing world. Our study does not enable us to answer the question how much laptop usage is beneficial for children; longitudinal studies are required to address this issue.

We also emphasize that it is important to establish which aspect(s) of usage caused this effect, and again whether effects can be generalized to other skills and abilities. Going beyond abstract reasoning, follow-up research needs to determine the impact of specific laptop activities on other cognitive outcomes, scholastic achievement, psychosocial development, and more broadly cultural change (e.g., Hansen & Postmes, 2012). It would also be interesting to investigate how much the content of the activities matters for advancing learning for specific topics versus more general skills. On the basis of the present results, it cannot be ruled out that positive changes in one domain (such as abstract reasoning) are paralleled by less positive changes in other domains (such as emotional development).

We have compared children who were using a laptop with a control group. Future research could compare the impact of other investments such as providing additional textbooks, professional development or additional teachers on students' performance. This comparison would allow drawing conclusions about the effectiveness of different types of investment.

Finally, it would be important to establish whether findings can be generalized to other cultural settings, where laptops may be used quite differently. In Ethiopia children are encouraged to use their laptop in school and take it home as well. Our study and another observation (Hollow, 2009) showed that laptops were hardly used in the classroom. However, students used their laptops frequently outside the classroom. Our results are in line with research in India where students performed better on standardized tests when a computer assisted learning program designed to reinforce students' understanding of material presented in class, was a complement rather than

[5] The effects were medium-to-large according to Cohen's (1977) guidelines.

a substitute for the teacher delivered curriculum (Linden, 2008). Unlike in other developing countries,[1] laptops were distributed with active involvement of the schools and teachers, who were all trained to use the laptops in class (Kocsev et al., 2009). This supportive environment may play a role in explaining the laptops' effects on abstract reasoning. Furthermore, the lack of most forms of societal modernization in Ethiopia may well have contributed to the magnitude of effects found in this study. Children's abstract reasoning in more developed countries might be less strongly affected by similar laptop programs because their skill level might already be higher (e.g., Gauvain & Munroe, 2009).

4.3. Implementation and challenges of laptop programs in developing countries

This paper has, so far, restricted itself to the impact of laptop usage on abstract reasoning skills. However, the implications of these results for the utility of laptop programs can only be assessed by taking the context into account. To begin with the characteristics of the present study: At the time of this research, quite soon after deployment, students were frequently using their laptops. We emphasize that the conditions under which this research was conducted were quite special: The few schools that had received these laptops received a lot of support such as professional development for teachers and digital schoolbooks.

In the broader context, there are a number of practical and ethical concerns that need to be taken into account. OLPC has itself received criticism by researchers, aid workers, politicians and other stakeholders for a number of reasons. Pilot studies showed that OLPC is often unsuitable for development contexts (e.g., Fox Buchele & Owusu-Aning, 2007; Leaning, 2010). Furthermore, the program has been criticized for its technical determinism, its lack of sensitivity to local contexts and cultures, and for its emphasis on the technology rather than on a coherent educational programme of learning with (or even about) technology (e.g., Leaning, 2010). Also, Wagner et al. (2005) have noted that many projects have had a variety of outcomes with negative impacts that include the reinforcing of dependencies and imposition without community involvement, as well as risks of longer-term collapse due to lack of funding or political commitment. Another question is whether this technology adequately meets the most pressing needs for the people in these communities, not least because of their cost relative to other forms of aid (e.g., Purington, 2010; Warschauer & Ames, 2010). And finally, especially relevant with respect to the present research project, there are legitimate ethical concerns regarding the utility and fairness of equipping only a few schools and classrooms with this equipment.

In sum, we emphasize that even though the present research findings provide some initial encouraging evidence for the effectiveness of these laptop programs, this by itself does *not* make investment in such technology worthwhile, sustainable and ethical.

4.4. Practical implications

Robust empirical evidence in this field is very scarce (Nugroho & Lonsdale, 2010; Penuel, 2006; Trucano, 2005). To date, the major limitation of empirical evidence is a lack of a suitable control group (Wagner et al., 2005). The current research set out to provide systematic insight into cognitive outcomes in one of the least developed countries. Empirical insight can not only enrich theorizing but is also of great interest for involved stakeholders to learn lessons to improve projects in the field of ICT for development.

Given that large sums of money are currently invested in laptop programs for students around the world, this insight should be of great interest for all involved stakeholders. Surprisingly, stakeholders often underestimate the magnitude of the initial investment required: In the local economy, this technology is a lot more expensive than are books, classrooms and teachers. There is also a tendency to neglect the significant oncost (e.g., Adhikari, 2011) for providing technical support such as repairs of broken laptops, mains electricity, or new software and to adopt these to the specific context (e.g., Warschauer & Ames, 2010). These additional investments are highly important for a sustainable success of these laptop programs for students in developing countries. Only with accompanying support (see also Warschauer & Ames, 2010) and sustainable interest of involved stakeholders (e.g., Unwin et al., 2010) can these programs have a lasting impact on students' development. At the same time, our data suggest that even with extensive professional development programs for teachers, laptop usage in class remained quite limited. Other research has shown that people are most likely to adopt new technologies if they experience personal benefits from using them (e.g., Kraut et al., 2002). Thus, it may be that software development needs to focus on the development of concrete activities that teachers can integrate into their lessons and that facilitate the teaching of specific topics.

4.5. Conclusions

Together, these findings comprise the first systematic evidence suggesting that laptops have positive learning outcomes on abstract reasoning abilities in one of the least developed countries. In an environment where children lack computer experience and are used to frontal teaching, using a laptop significantly boosted students' development of abstract reasoning. These effects appear to be relatively strong compared with effects found in comparable studies in developed countries. Considering the fundamental importance of abstract reasoning in everyday life and its predictive power for a variety of intellectual tasks and educational outcomes, we suggest that our findings provide some tentative evidence that the use of a laptop may bring some meaningful benefits for children in the developing world.

Appendix A

Table A1
Overview and description of all activities installed on laptops in Ethiopia.

Activity	Description
BlockParty	Game better known as Tetris
Browse	Simple application used for documentation about history, biology, pictures and as portal to open schoolbooks
Calculator	Standard calculator
Chat	Environment for discussion between two or more individuals within a radius of 10 m
Distance	Collaborative activity that can be used to measure distances with other laptops
Etoys	Environment providing children with a simple programming language to create models, simulations, or games with text, graphics and video. Furthermore, Etoys has built in games such as chess.
Journal	Chronological diary of children's actions on the laptop, used to revisit past project and files or for parents and teachers to assess a child's progress.
Maze	(Collaborative) game with different series of mazes. After every passed level a more complex maze is entered.
Memorize	Memory game in which two items that belong together should be identified, with possibilities for 4 × 4, 5 × 5 or 6 × 6 design. Items can be arithmetic (combine calculation with solution), with letters or with sounds.
Pacman	Game in which the player tries to eat all dots in a maze. Can be played together with other children.
Paint	Application to make drawings. In Etoys, it is possible to open paint to make drawings for own programmed animations.
Read	Basic PDF or document viewer
Record	Application to take pictures or record videos
Speak	Speaking tool. Words that are entered in a field will be spoken aloud. Children can control the language and different aspects of the voice.
Tam Tam Edit; Jam/mini/ SynthLab	Environments to get acquainted with music to perform music (either alone or together), and to compose music. Different types of instruments, sounds and rhythms are introduced and object of play.
Wikibrowse	Reference material for different subjects
Write	A basic text editor

Table A2
Mean scores and effect sizes on the subtests analogies and categories for children without or with laptops for each grade (*SD*s in brackets).

	No Laptop			Laptop			*d*-scores	
Variable	*N*	Analogies	Categories	*n*	Analogies	Categories	Analogies	Categories
Grade 5	103	13.87 (4.17)	9.73 (4.22)	87	13.17 (4.82)	9.72 (4.73)	.15	.00
Grade 6	81	14.14_b (4.87)	10.31_b (4.32)	85	16.82_a (5.63)	12.42_a (4.85)	.52	.47
Grade 7	26	16.00_b (5.26)	12.62_b (5.12)	31	20.71_a (4.42)	15.81_a (5.38)	.88	.58
Total	210	14.24_b (4.62)	10.31_b (4.45)	203	15.58_a (5.75)	11.78_a (5.30)	.31	.30

Note: For each subtest, means within each row with different subscripts differ significantly at $p < .05$, means with no subscripts do not differ significantly.

Table A3
Mean scores and standard deviations on the average, Math, and English grades for children without or with laptops before laptop deployment (*t*1) and at the end of the semester after deployment (*t*2), broken down per grade ($N = 413$).

	No Laptop						Laptop					
Variable	Average grade		Math grade		English grade		Average grade		Math grade		English grade	
Semester	*t*1	*t*2	*t*1	*t*2	*t*1	*t*2	*t*1	*t*2	*t*1	*t*2	*t*1	*t*2
Grade 5	64.65 (11.70)	70.85 (9.66)	57.63 (13.50)	67.48 (12.12)	55.97 (17.75)	60.33 (16.04)	66.20 (9.24)	68.50 (8.55)	58.78 (14.56)	60.17 (11.23)	61.59 (17.63)	62.32 (16.46)
Grade 6	67.36 (8.82)	66.25 (9.39)	59.00 (10.84)	52.92 (10.33)	65.78 (16.01)	60.77 (15.42)	65.78 (9.61)	65.55 (10.48)	60.60 (15.38)	59.49 (11.56)	59.45 (14.54)	56.15 (12.44)
Grade 7	67.23 (8.74)	71.22 (8.44)	60.62 (9.48)	58.96 (9.82)	67.23 (9.73)	70.62 (11.04)	64.16 (9.46)	67.98 (8.59)	58.19 (10.14)	54.97 (9.20)	60.68 (11.77)	67.35 (9.38)

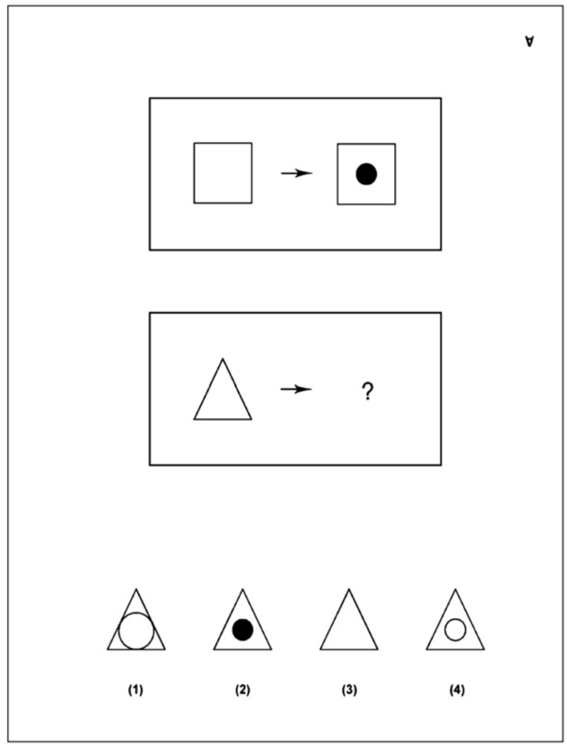

Fig. A1. Example A of subtest Analogies from the subject's point of view (the correct solution is alternative 2). By changes in one or more aspects of the figure in front of the arrow, the figure behind the arrow is created. Children are asked which of the four figures should replace the question mark. The answer is given by applying the transformation in the top row to the middle row.

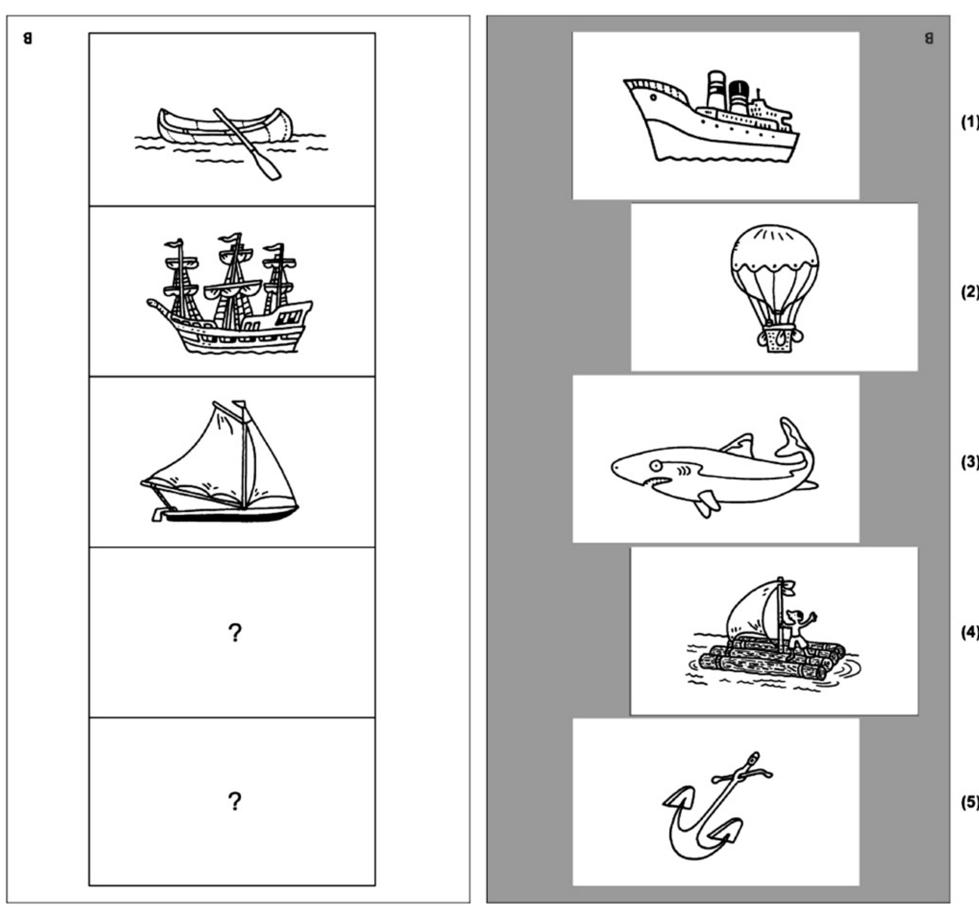

Fig. A2. Example B of subtest Categories from the subject's point of view (the correct solution is 1 and 4). The child is asked which of the pictures 1–5 are from the same category as the three pictures on the left. In order to answer this question, the respondent has to discover the concept underlying the three pictures and apply them to novel images.

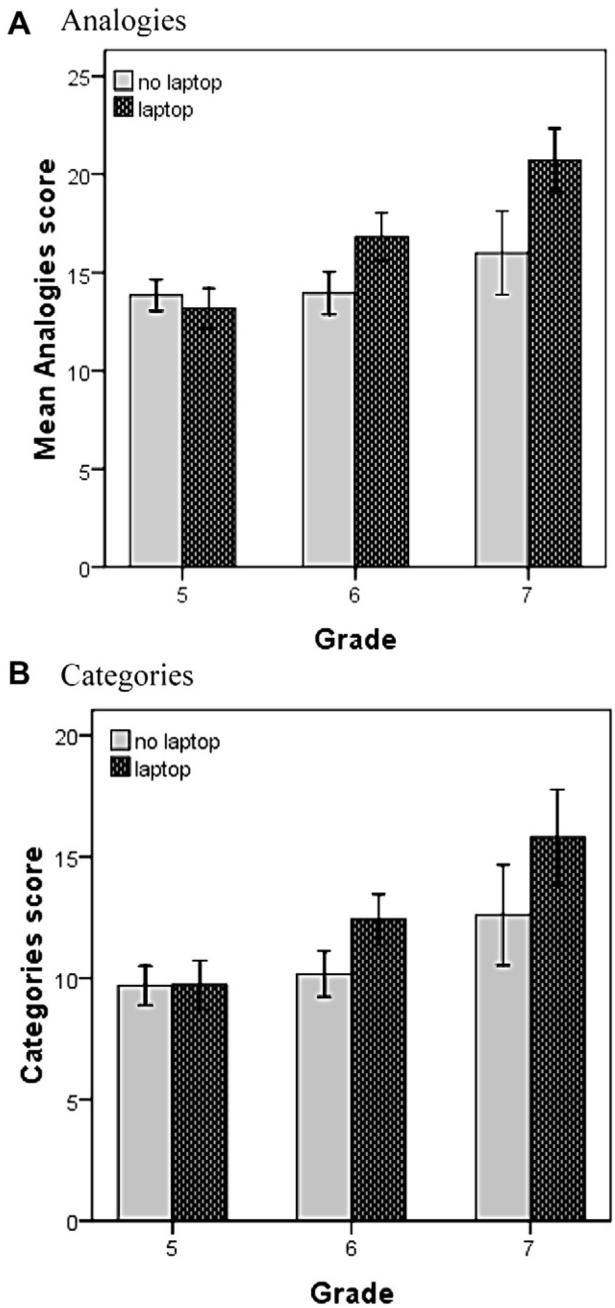

Fig. A3. Abstract reasoning abilities as a function of grade and laptop. Mean scores and 95% confidence intervals on the analogies subtest (A, see Fig. A1) and the categories subtest (B, see Fig. A2) of the revised version of the Non-verbal intelligence test SON-R 6-40.

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