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The effect of individualized digital practice at home on math skills—Evidence from a two-stage experiment on whether and why it works

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ABSTRACT

This paper analyses an experiment on the effect of an individualized, digital practice tool on numeracy skills for 337 seventh grade students. The first stage of the experiment shows that offering students the opportunity to practice numeracy digitally at home (intent-to-treat) leads to a substantial and significant increase in numeracy performance growth. The second stage reveals that the effectiveness of the tool mainly stems from its individualized nature. With good implementation prospects and relatively low costs, the consequences are discussed to be potentially large.

1. Introduction

Basic math and language skills (numeracy and literacy) are generally recognized as major components of human capital. Furthermore, they are important in the daily functioning of potentially every human being and they are well documented to contribute to labor market success (see e.g. Chiswick, Lee, & Miller, 2003; Hanushek, Schwerdt, Wiederhold, & Woessman, 2013; Vignoles, De Coulon, & Mercenaro-Gutierrez, 2011). Despite this seemingly self-evident statement, many students are observed not to have sufficient basic math and language skills (Funnekotter, 2012; KNAW, 2009; OECD, 2013). In the Netherlands, for example, both a special parliamentary commission (Commissie Meijerink, 2008) and the Royal Netherlands Academy of Arts and Sciences (KNAW, 2009) concluded some years ago that urgent action was required, because an increasing number of students lack the necessary numeracy and literacy skills. This call for action has led to the introduction of a compulsory numeracy section in the already existing national graduation exam program for secondary education. In turn, the

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introduction of these exams has motivated schools to formulate policy documents on how to improve numeracy and literacy skills in the most efficient way.

The policy plans draw on the scientific consensus that individual differentiation is the key to higher student performance (e.g. Hattie, 2009), where traditional classroom settings only partly allow schools to differentiate their teaching between individual students. The combination of the increase in computer use in education, the need for individualization in the learning process and the decrease in basic math and language skills has led to the development of individualized Information Technology (IT)-tools aimed at developing these skills, especially in K-12. Accordingly, in their search to improve students' numeracy and literacy skills, many schools started using individualized IT-tools, often outside regular school hours (at home). This seems comparable to the digital tutoring in the out-of-school-time program, although many Dutch schools use it for *all* students and not just disadvantaged students (see e.g. Heinrich et al., 2014). Individualized IT-tools focus on an individual learning path for the student, adapting the exercises available for the student to the skills that he or she is lacking.

However, the existing literature contains only few experimental studies on the effect of IT-tools on numeracy and literacy performance (Arroyo, Park Woolf, Royer, Tai, & English, 2010; Barrow, Markman, & Rouse, 2009; Borman, Benson, & Overman, 2008; Pilli & Aksu, 2013; Rouse & Krueger, 2004). Furthermore, it is unclear how best to use these IT-tools, e.g. with respect to where and when to practice or the amount of teacher involvement. Hence, it is unclear whether these schools chose an effective teaching program and use it in an effective way.

Therefore, the purpose of this paper is, first of all, to analyze the effect of individualized educational software developed in the context of the above described policy change in the Netherlands. Furthermore, the purpose is to analyze *why* this software is effective and under what circumstances it is most effective. We conduct an experiment with an interactive digital practice tool and analyze the effects of offering this tool to students (intent-to-treat) on numeracy performance of students in 7th grade (age 12, first year of secondary school in the Netherlands). In this experiment, we are able to also take into account the intensity of treatment and the influence of the teacher. In the first stage, we show that the effect of the digital practice tool is about 0.40 of a standard deviation. Furthermore, we show that the non-compulsory training complements class-based training and is effective regardless of the math class and the teacher and the teachers' attitude towards the tool. The second stage shows that the effectiveness of the digital practice tool is due to the individualized differentiation (similar to the finding in Barrow et al., 2009).

In the literature, we see that many of the previous evaluations of information technology (IT) are wide in scope, as they evaluate, for example, increased budgets for IT either for schools or for households. They rely on the assumption that users have sufficient skills to implement and use IT to their benefit and that it does not matter how IT is used, in order to benefit educational outcomes. Yet, in practice, these general evaluations offer mixed results (e.g. no significant effect of IT: Goolsbee and Guryan (2006); positive effect of IT: Machin, McNally, and Silva (2007); negative effect of IT: Angrist and Lavy (2002), Leuven, Lindahl, Oosterbeek, and Webbink (2007)).

A second part of the literature on IT focuses on the comparison of computer directed versus traditional classroom teaching. A couple of meta-analyses apply strict selection criteria with respect to methodology used in the individual studies (Cheung & Slavin, 2012, 2013; Kulik & Kulik, 1991; Means, Toyama, Murphy, Bakia, & Jones, 2010) and show that in general, computer directed instruction does have small positive effects on student performance, compared with traditional classroom teaching, for both math and language.

Thirdly, IT proves particularly suited to provide individualized differentiation (from now on: individualization), with its algorithms allowing for individual learning paths. Incorporating the differences in level, interests and learning styles between students is shown to improve students' motivation (Tomlinson, 2004), and neglecting these differences might lead to decreased performance of certain students (Tomlinson & Kalbfleisch, 1998).

Evaluations of IT-based individualization programs in math and numeracy range from general teaching to remedial programs and cover both general student audiences and students with learning disabilities. In general, evaluation outcomes tend to be positive. Burns, Kanive, and DeGrande (2012) show that significantly fewer of the students at risk for math difficulties before, were still at risk after using a computer delivered math fact intervention. Similar results are found by Pilli and Aksu (2013). Banerjee, Cole, Dufflo, and Linden (2007) report on the positive outcomes of an experiment with an IT-based math remedial program, introduced in public schools of two cities in India, which illustrates that the benefits of IT-individualization are not confined to students from highly technologized societies.

The before mentioned three studies all analyzed 3rd and/or 4th grade students. There are only a few academic publication using a similar age group as in the study at hand. Arroyo et al. (2010) analyzed 250 7th and 8th grade students that used a digital skill drill method, or traditional practicing on paper, 15 min per day next to math classes, for four days, and find a significant positive effect of digital practicing. Barrow et al. (2009) also perform a randomized experiment, under 1605 middle and high school students, and show that treated students score significantly higher on pre-algebra and algebra skills than their counterparts who received traditional instruction.

Although it is possible that publication bias distorts the conclusions on specific programs more than in the case of the general IT evaluation, the former group of evaluations offers a range of positive experiences to build on. However, they do not go into detail in why these tools work or how to implement them. Furthermore, a potential hindrance to the rapid expansion of educational innovation through IT is acceptance by teachers. On the one hand, teachers often do not want interference in their classroom, and especially elder teachers often do not believe in the benefits of IT training. On the other hand, interventions and innovations are often imposed by the management, without consulting the teachers, which also might lead to resistance by teachers. As we study the introduction of a type of software that does not require a large teacher investment,