

Beyond One-Size-Fits-All

Differential Effects of Analogue and Digital Collaborative Student-Centred Reading Interventions in Primary Education

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Abstract

This study investigates the effectiveness of analogue and digital reading interventions in heterogeneous primary school classes, examining how student characteristics influence intervention outcomes. Using data from 15 third-grade classes participating in the «Digital Equity» project, we implemented collaborative, student-centred reading interventions in both analogue and digital formats. The study employed a quasi-experimental pre-post design with multilevel modeling and recursive partitioning to identify differential intervention effects. Results reveal that intervention effectiveness varies significantly across student subgroups. While conventional analyses showed only marginal effects, algorithm-based subgroup analyses identified that highly motivated girls benefited significantly from analogue interventions. Digital interventions showed no positive effects, and surprisingly, frequent digital media users responded negatively to digital reading formats. These findings challenge assumptions about universal classroom interventions and digital learning, suggesting the need for more targeted, differentiated approaches to reading instruction that account for individual student characteristics.

Jenseits von Standardansätzen. Differenzielle Wirkungen kollaborativer, schülerzentrierter Leseinterventionen in analogen und digitalen Lehr- und Lernsettings in der Grundschule

Zusammenfassung

Diese Studie untersucht die Wirksamkeit analoger und digitaler Leseinterventionen in heterogenen Grundschulklassen und analysiert, wie Schülermerkmale die Interventionsergebnisse beeinflussen. Anhand von Daten aus 15 dritten Klassen im Rahmen des «Digitale Chancengerechtigkeit» Projekts wurden kollaborative, schülerzentrierte Leseinterventionen sowohl in analoger als auch digitaler Form implementiert. Die Studie verwendete ein quasi-experimentelles Prä-Post-Design mit Mehrebenenmodellierung und rekursiver Partitionierung zur Identifizierung differentieller Interventionseffekte. Die Ergebnisse zeigen, dass die Wirksamkeit der Interventionen zwischen Schülergruppen erheblich variiert. Während konventionelle Analysen nur marginale Effekte aufzeigen, identifizierten algorithmusbasierte Subgruppenanalysen, dass hochmotivierte Mädchen signifikant von analogen Interventionen profitieren. Digitale Interventionen zeigten keine positiven Effekte, und überraschenderweise reagierten häufige digitale Mediennutzer negativ auf digitale Leseformate. Diese Erkenntnisse stellen Annahmen über universelle Klasseninterventionen und digitales Lernen in Frage und deuten auf die Notwendigkeit gezielter, differenzierter Ansätze im Leseunterricht hin, die individuelle Schülermerkmale berücksichtigen.

1. Increasingly Heterogeneous Primary School Classes

Managing diversity is a central challenge for primary school teachers (Dietrich and Riepe 2019; Miller 2021). The significance of diversity-sensitive teaching skills has increased as more children with migration backgrounds enter primary school classes (Destatis 2023) and as demands for implementing inclusive education, in line with the UN Convention on the Rights of Persons with Disabilities, continue to rise (Seitz 2020). While primary school classes are becoming increasingly diverse (Educational Reporting Group 2022, 142 ff.), the objective of achieving educational equity persists. This situation reveals a paradox: despite the ongoing commitment to educational equity since the era of educational expansion, the promised establishment of educational equity has not been fulfilled since the educational expansion (Bachsleitner et al. 2022; Wendt and Hußmann 2019). At the same time, educational equity remains connected to emerging discourses, such as inclusion (Budde et al. 2020), diversity-oriented teaching and learning settings, and sustainability (WBGU 2019), thus retaining its normative significance.

These developments intersect with the digital transformation, which in turn poses new challenges for education. In this context, Germany continues to lag significantly behind other countries in international comparison of digital education practices

(Eickelmann et al. 2019). This gap persists in both the availability of digital media and the ways in which they are employed. When digital tools are used, they are generally regarded as instruments for optimizing learning processes rather than as integral elements of an evolving digital society (Hauck-Thum and Noller 2021). Meanwhile, empirical evidence on the use of digital media and social networks indicates that children are autonomously acquiring informal digital competencies in their everyday lives (Feierabend et al. 2023).

To address the increasingly heterogeneous starting points of students in the context of broad societal changes, adaptations are required across various educational levels (such as classrooms, school leadership, policy) (Heinz 2023). In this article, we address the classroom level. In the Digital Equity project (Heinz and Hauck-Thum 2020), we aimed to investigate how teaching and learning settings can be designed to facilitate participation for children with diverse starting points, individual characteristics, and media preferences. The project involved developing, implementing, and evaluating learner-centred, creative, and collaborative teaching and learning settings in both digital and analogue formats (Franz and Eichmann 2022).

The article begins with a brief presentation of the theoretical approach, emphasizing the alignment between informal knowledge and academic requirements. This is followed by an overview of current research on the development of reading competence, considering factors such as motivation, socioeconomic background, gender, migration status, and the impact of digital and analogue media. The subsequent sections introduce the project, describe the sample and the variables used, and then present and discuss the results.

2. Gaps Between Life-World Knowledge and Academic Requirements

Following Bourdieu's concepts of habitus and field, educational practice in social milieus appears as part of overall class reproduction strategies (Bourdieu et al. 1971). The social milieu focuses both the «objective» features of social status and the «individual» everyday practice in which education and praxeological educational strategies are embedded. Based on these concepts, Bremer and Lange-Vester (2015) argue that the diversity of social contexts in education should be seen as more than just a neutral variety; it is rather permeated by power and dominance effects that manifest specifically in the educational field. Drawing on Bourdieu's theory, Kramer and Helsper (2010) underscore the gap between school requirements and different life contexts, which leads to alignment conflicts between students' familial habitus, their competencies, and the «implicit» habitus expected by schools (Bremer and Lange-Vester 2015). Dalhaus similarly highlights this issue in her concept of «Individual Educational Knowledge» (Dalhaus 2010; 2011). She distinguishes between children's life-world and everyday world, including schools. She highlights significant gaps in meaning between the individual educational knowledge children acquire in their parental homes and the demands of institutions

like schools. While the former manifests as specific forms of relationship competence (e. g., exchange or cooperation), the latter requires more subject-specialized knowledge (Dalhaus 2011, 123). These meaning gaps vary in size depending on students' social background. For example, students from socially disadvantaged backgrounds would tend to respect teachers unquestioningly while reacting to academic expectations with defiance and school drop-out (Dalhaus 2011). Moreover, educational research results show that often families with low socioeconomic status do not foster cognitive, motivational, linguistic, and social skills that facilitate academic success (Kramer and Helsper 2010; Wohlkinger and Bayer 2020). This creates a misalignment with the performance and educational requirements of educational institutions, which tend to align with middle-class values, practices, and knowledge (Ecarius et al. 2011). School personnel also contribute – whether consciously or unconsciously – to the consolidation of background-specific educational opportunities by presupposing precisely that knowledge and those behaviours particularly attributed to middle and upper social classes.

To achieve better alignment of teaching with the informal, individual educational knowledge of children from diverse cultural and socioeconomic backgrounds, school teaching and learning settings must open up to these diverse prior experiences of children. It is essential to acknowledge students' prior knowledge while using it as a foundation for educational development and learning processes, making it applicable to school requirements (Cook, Pachler, and Bachmair 2013, 37–38). Lower-performing students need additional support in this regard (Heinz 2023). Simultaneously, educational programs should avoid reinforcing gender- and milieu-specific stereotypes to prevent exacerbating existing disparities among children with diverse starting points.

Based on these considerations, the «Digital Equity» project has designed learning environments for a student-centred, collaborative German language instruction (Hauck-Thum and Franz 2023), focusing on improving reading competency. Before we provide an overview of the project and the developed teaching and learning settings, we will present the current state of research on inclusive approaches to promoting reading competency in primary school.

3. Reading Competency and Reading Motivation in Relation to Social Background, Migration Status, and Gender

Reading is a key competency and central to knowledge acquisition, academic and professional success, as well as social participation (Ludewig et al. 2022). However, national and international studies indicate that reading competency has declined since 2006, particularly between 2016 and 2021 (McElvany et al. 2023). Fourth-grade students in Germany perform around the average internationally, and there are significant disparities between strong and weak readers, with the gap widening in recent years. Most concerning, a quarter of the tested children in Germany do not reach the internationally

established minimum standard for reading, and this proportion has increased significantly compared to 2016. In particular, the proportion of students with only rudimentary reading skill (competency level I) has more than doubled from 2001 to 2021 – from 3% to 6.4% (ibid.).

Differences in reading competencies are often attributed to socioeconomic background and migration status. There is a considerable performance gap between children from disadvantaged socioeconomic or migrant backgrounds and children from more privileged families. Between 2016 and 2019, this gap in German equaled approximately one school year, according to educational reports (Educational Reporting Group 2022). Children who sometimes or never speak German at home perform significantly worse in reading than those who do, with a gap of roughly one school year (McElvany et al. 2023). Similarly, disparities based on socioeconomic status amount to about 42 points.

Regarding gender, the IGLU 2021 report found that girls outperform boys in reading by 15 points. Girls also display higher reading motivation and a more positive self-assessment of their reading competence compared to boys (McElvany et al. 2023). These differences between girls and boys are largely attributable to gender-specific biases, which are also evident in how teachers assess students' abilities (Muntoni et al. 2021). Meta-analyses by Olczyk et al. (2023) show that primary school teachers tend to rate girls more favorably in language subjects while underestimating them in mathematics. These biased judgments can partly predict future student performance, independent of previous achievement.

Reading motivation is an important predictor for reading competency (Ohle-Peters et al. 2021). Numerous studies show stronger reading competency correlates with higher intrinsic reading motivation (willingness to read because this activity is rewarding or satisfying for oneself, e. g. out of interest or enjoyment of the topic) (Pfaff-Rüdiger 2011; Schwabe et al. 2021). The relationship between intrinsic reading motivation and reading competency is reciprocal, e. g. they influence each other (Goy, Valtin, and Hußmann 2017; Miyamoto, Pfost, and Artelt 2018; Ohle-Peters et al. 2021). Intrinsic reading motivation boosts reading competency by increasing reading frequency, while high reading competency, in turn, fosters higher reading motivation (Mentel et al. 2022).

While children's reading motivation in Germany is high by international comparison, it has decreased over the past 20 years, with the percentage of children who enjoy reading dropping from 76% in 2001 to 69.9% in 2021 (McElvany et al. 2023). Similar to reading competency, reading motivation is also associated with socioeconomic background and gender. Thus, higher motivation levels are observed among children from higher socioeconomic status and families with higher parental educational attainment (McElvany, Becker, and Lüdtke 2009). Throughout primary school, there is a general decline in reading motivation, reading self-concept, and reading behaviour. Boys in particular often show more negative reading-related characteristics at the end of primary school.

4. Programs to Enhance Reading Competency

National and international research show that effective reading programs address children's individual prerequisites and target various aspects of reading competency. For example, weak readers without migration background benefit from exercises that strengthen basic reading processes, such as word recognition, decoding, promoting reading fluency, and vocabulary expansion (Gailberger et al. 2021; Ludewig et al. 2022; Therrien 2004). In contrast, children with higher reading competency improve through training in cognitive and metacognitive reading strategies for text comprehension (Dinsmore et al. 2020; Philipp 2015; Schilcher et al. 2022). Additionally, cooperative learning settings like reciprocal reading can increase effectiveness of reading strategies for text comprehension (Mentel et al. 2022). Children whose native language is not the language spoken in class benefit from additional vocabulary training, decoding and language comprehension exercises to learn the instructional language as a second language. The promotion of reading motivation, however, appears to be more complex. Recommendations include focusing on intrinsic reading motivation in primary school (Ohle-Peters et al. 2021; Locher 2020). To prevent potential declines in motivation, didactic measures are recommended, such as providing reading materials that are relevant to children's lives and incorporating regular reading training (Vach 2018). Regarding reading instruction, Schiefele and Osburg (2018) emphasize the importance of a positive reading self-concept and active engagement with texts. However, evidence-based evaluations of such programs predominantly show small or no positive effects (Förster 2018; Mentel et al. 2022; Ohle-Peters et al. 2021).

Moreover, research suggests that reading promotion is most effective when programs are tailored to children's needs and adopt a multidimensional approach. However, there is limited research on the moderating factors that affect the application of these programs in schools (Philipp and Jambor-Fahlen 2022). Walter (2020) reported positive short- and medium-term transfer effects on standardized reading comprehension assessments for fourth graders in an intervention targeting struggling readers. The intervention program «We Become Text Detectives» (Gold et al. 2004), focused on teaching text reading strategies and was adapted to students' prerequisites. The program included effective instructional characteristics (motivational support and structured instruction, peer interactions, use of contingency management, hint cards, corrective feedback, and individual evaluation procedures), expanded through additional lessons, applied only to particularly weak readers, and was implemented by comprehensively trained teachers who had experience in supporting weak readers. The program's evaluation showed significant improvements in reading fluency and comprehension. While the intervention focused on improving comprehension-based reading competency, Walter (2020) highlights in discussing the results that the positive effects of the intervention were attributable not only to the teaching of reading strategies but particularly also to supporting weak readers in word reading and reading fluency. Accordingly, he advocates for

multidimensional reading programs that promote, for example, vocabulary and reading fluency alongside reading strategies.

Similarly, Lauer-Schmaltz et al. (2014) emphasize in their study on the effectiveness of oral reading tandems for improving reading fluency the importance of tailoring reading texts to children's individual abilities. Their study found only small effects and large heterogeneity in children's reading fluency levels. The authors conclude that the difficulty level of texts was not adequately matched to the readers' individual skill levels, leading to some children being overwhelmed while others were not sufficiently challenged, thus limiting the potential impact of the intervention.

International research shows that effective reading programs for elementary students often involve a combination of instructional process changes, one-to-one tutoring, and mixed-method approaches (Cortes et al. 2025; Nurmahanani 2023; Slavin et al. 2009). Early intervention, a focus on phonics, and professional development for teachers are critical components of successful programs (Prescott et al. 2018). While challenges in implementation and scaling exist, innovative approaches like blended learning and targeted vocabulary instruction offer promising solutions for improving reading outcomes (Cockerill 2021; Slavin et al. 2008).

5. Reading in a Digital Society

Recent studies detailed how reading competency and reading motivation differ depending on digital and analogue media. Rothe et al. (2022) compared the reading performance of 237 third and fourth graders in digital and analogue test formats and found no significant differences in the number of correct words read in five minutes. However, analogue reading showed better comprehension outcomes compared to digital texts, in particular when children read non-fictional texts and had a time limit (Delgado et al. 2018; Sidi et al. 2017). Digital reading, on the other hand, seems more suitable for quick and sometimes superficial reading (Hooper and Herath 2014). Thus, the type of text and its potential to stimulate immersive reading plays a role. In their meta-study, Delgado et al. (2018) found that readers understand non-fiction texts better when presented in print. Schwabe et al. (2022) noted a slight advantage for digital narrative texts that include multimedia and interactive features, such as an integrated dictionary and voice output, which can enhance reading comprehension. Similarly, Dahlström and Boström (2017) found in their study with Swedish fourth graders that children's text comprehension improved when voice output was used: When learners can repeatedly hear their texts, they improve in terms of the length of texts read, spelling, structure, and content.

Furthermore, digital tools can also provide targeted support for children with reading and writing difficulties, for example through the use of voice output, spell checkers, and the use of interactive e-books that allow word prediction (Jing and Chen 2017). To be effective, these digital tools must match students' written language level and account

for their media competency. Additionally, digital tools can have a positive impact when they promote phonological awareness, letter recognition, and reading and writing strategies. Features such as task adaptability, feedback, progress monitoring, repetition, and rewards have shown positive impacts (Cordes et al. 2023).

Studies show that student characteristics such as gender, migration status, and socioeconomic background influence the handling of digital media and reading preferences. Thus, McElvany and Schwabe (2019) identified gender-specific differences in reading motivation and self-concept, with girls showing higher overall motivation, which extended to digital reading despite having lower digital media-related motivation than boys. Furthermore, socioeconomic background affects digital media use. Accordingly, individuals with low educational levels tend to use the internet more for leisure than educational purposes (van Deursen and van Dijk 2014), while less privileged students are more likely to engage in online gaming and social networking than reading news or accessing academic information (OECD 2019, 146). Schools also show differences in digital media use based on socioeconomic status. Ma (2021) found that students in higher-status schools are more likely to use digital media for learning and exhibit better digital skills than their peers in lower-status schools. In resource-poor schools, computers are often used for repetition and basic skill practice (Warschauer 2016), yielding fewer learning benefits than the creative, constructive uses encouraged in higher-status schools (Wenglinsky 2005).

In summary, these findings of national and international research highlight the need for reading instruction to be inclusive and adaptable to the diverse skill levels of students. Effective programs should offer a multidimensional approach, addressing both foundational and higher-level reading competence responding to the evolving reading preferences shaped by cultural and technological changes.

6. Background to the «Digital Equity» Project

This analysis draws on data from the BMBF funded project «Digital Equity» employing a multi-method approach aimed at examining the connections between students' social and individual characteristics, their reading competence, and motivation in reading and literature instruction classes, and how their reading competences benefit from analogue and digital teaching and learning settings (Franz and Eichmann 2022).⁹

The instructional design was guided by research on acquiring reading competencies in heterogeneous classes. Reading in the intervention groups comprised four consecutive phases:

9 The data is freely accessible in the research database of the German Youth Institute, see Heinz et al. (2023).

1. Reading phase: Students select reading materials that present a range of perspectives based on their interest. The reading phase includes reading tandems, an evidence-based approach shown to enhance individual reading competence (Lauer-Schmaltz et al. 2014). Activities to ensure text comprehension follow this phase.
2. Discourse phase: Students participate in small-group discussions that revolve around specific problems, engaging in language negotiation processes aimed at developing their linguistic skills.
3. Creative implementation: The results of the discussions are presented through various formats. This phase connects with children's prior knowledge and individual experiences (Dalhaus 2011), enabling them to co-creatively design formats based on their preferences (Hauck-Thum and Heinz 2021).
4. Reflection: Students are given the opportunity to playfully explore different life perspectives, attitudes, and social roles through role playing and working in teams.

To assess the impact of instructional methods and the role of different media formats (analog/digital), the modified teaching and learning settings were implemented in both analogue and digital versions. In one group (consisting of five classes), students worked with analogue books, chosen to reflect the diverse backgrounds of the students (analog intervention group). In a second group (again five school classes), students interacted with the same books presented as multimodal texts on tablets (adaptable books), which integrated print with audio and visual elements (digital intervention group). The digital format allowed students to personalize their reading experience by adjusting text features and combining text, audio, and images in line with their media preferences (Hauck-Thum 2018). These multimodal texts offer potential to address the students' diverse learning needs, prior knowledge, and individual preferences.

A central hypothesis is that these interventions will better address individual reading preferences, informal competencies, and individual reading competencies, as all students are actively involved in reading, discussing the texts, and presenting solutions to problems in collaborative teaching settings. These settings provide space for students' diverse individual informal knowledge. Aligning students' individual knowledge with formal educational settings and employing a multidimensional reading approach could foster improvements in reading competence for all students.

7. Research Questions

This contribution is based on two research questions:

- To what extent does the medium of instruction (analog or digital) in reading and literature education influence students' reading competency development?
- How do individual differences in students' sociodemographic backgrounds and personal characteristics moderate the effectiveness of these instructional approaches?

8. Data Collection and Analysis Method

Data: The allocation of the 15 classes to the two intervention groups and one control group was partially randomized, as entire classes were assigned to the two intervention groups and one control group. In the first and second schools, both digital and analogue interventions as well as control groups were used. In the third school, there were only analogue interventions and control classes, as there was no access to digital tools. We evaluated the intervention using a pre-post design. Students completed questionnaires assessing their reading motivation and media use. They also participated in standardized tests to measure their reading competence. Parents also completed questionnaires requesting information about their background.

Reading competence was measured at 3 measurement points (MTP) using the standardized reading test ELFE II – A Reading Comprehension Test for First to Seventh Graders (Lenhard et al. 2017), with the intervention taking place between the first and second MTP. Before the first survey and test, parents were informed in writing about the project, the handling of personal data, and data protection regulations. They were also asked for consent regarding their children's participation. Of the total 350 children in the 15 classes, 71 % of parents (n = 249) had given their consent by the start of the evaluation.

9. Analysis

To investigate our research questions, multilevel models are first used to examine whether the described interventions had effects on the development of reading abilities across all children. In a second, exploratory step, tree-based algorithms for multilevel models are used to identify whether subgroups can be identified based on the control variables that respond particularly well to the intervention.

The multilevel model was specified using the lme4 package (Bates et al. 2015) in R (R version 4.3.1) to estimate changes in reading skill $y_{\{Reading\ Skill\}}$ between measurement time points t . For this purpose, both random effects for individual average values $v_{\{i\}}$ and temporal development t within the studied schools $u_{\{ts\}}$ were modeled, as individual students had different starting values and schools showed different learning increases (see Fig. 1)

$$y_{\{Reading\ Skill\}} = \beta_0 + \beta_{\{Intervention\}} + u_{\{ts\}} + v_{\{i\}} + \epsilon_{\{ijk\}}$$

In this way, individual changes between the measurement time points can be estimated depending on the intervention, and both individual starting values and school-specific learning differences can be modeled.

In a second step, using the *glmtree* package (Fokkema et al. 2018), we investigated to what extent subgroups (*g*) can be formed based on the control variables between which the effect of the intervention $\beta_{\{g, Intervention\}}$ on reading ability differs maximally. This method goes beyond conventional classification trees as it does not search for subgroups based on maximum differences in variable expressions, but rather maximizes differences in relationships, i. e., in a linear model. The aim of the procedure is to identify subgroups in which the effects of our intervention on reading ability are maximally different. The control variables serve as splitting variables, meaning subgroups are defined based on their different expressions. The $\beta_{\{g, Intervention\}}$ are estimated locally as fixed effects in each individual group, while the random effects $u_{\{ts\}}$ and $v_{\{it\}}$ are estimated globally for all groups. In this way, algorithm-based subgroups can be formed that respond as heterogeneously as possible to the intervention.

A critical consideration in tree-based models is the selection of the minimum node size, which determines the smallest allowed subgroup in the tree structure. This parameter substantially influences both model complexity and stability: too small node sizes may lead to overfitting and unstable trees, while too large node sizes might mask meaningful subgroup differences (Fokkema et al. 2018). To empirically determine the optimal minimum node size for our longitudinal data structure, we conducted a bootstrap stability analysis following the approach outlined by Philipp et al. (2016) and Hothorn et al. (2006). We tested node sizes ranging from 30 to 90 observations (in steps of 15) using 100 bootstrap replicates for each size, analyzing the resulting distribution of terminal nodes to assess model stability and complexity. This analysis enabled us to select a node size that balances the trade-off between detecting meaningful subgroup differences and maintaining stable parameter estimates within nodes. The minimum group size is set to 45 to consider at least 15 children with 3 measurement time points each, and the significance level for possible splits is set to 0.001. This specification not only balanced the trade-off between detecting meaningful subgroup differences and maintaining stable parameter estimates, but also naturally selected only the most robust predictors identified by *stabletree* (Philipp et al. 2016) – namely motivation as the primary predictor, followed by moderately stable gender and media usage effects, while appropriately excluding less reliable predictors like education and language. For detailed results, see Appendix Table A1 and A2 and Figures A1-A4.

10. Variables

Table 1 provides an overview of the variables used. In addition to reading competence and intervention, children's gender was collected using a dummy variable (girl 51 %/ boy 49 %). Since no household income data is available, parental education (no parent with university degree 31 %/at least one parent with university degree 69 %) serves as a proxy for socioeconomic background. Reading motivation is measured on a scale from

1 to 4 (mean=3.2, sd=.8), based on the IGLU reading motivation index, which includes items such as «I would be happy if someone gave me something to read,» «I find reading boring», and «I like to read» (Cronbach's $\alpha = .75$; see Hußmann et al. 2017). The language spoken in the household is also recorded (German 50% /mixed: German and another language or other than German 50%).

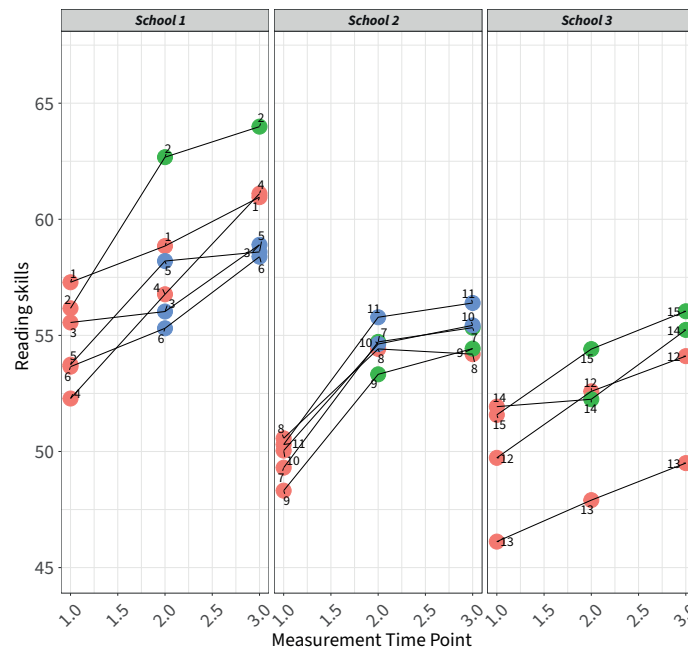
Parents were also asked about their child's frequency of media use, with different items asking about usage during the week and on weekends combined into an index ranging from 1 to 5, where 5 means that more than 2 hours of media are consumed daily (mean 2.7, sd=1). All variables except reading ability and intervention are time-invariant and represent values at measurement point 1. An overview of the variables can be found in Table 1. Appendix Table A1 shows results for tests whether there are significant differences in the distribution of the variables mentioned in relation to our analogue and digital treatment, i.e. whether there is selection, which is not the case.

Variable	Mean	Sd	NotNA	Min	Max
Reading skills	52	8.4	218	26	66
Intervention	246				
... No Treatment	75	30%			
... Analogue	89	36%			
... Digital	82	33%			
Gender	246				
... Girl	126	51%			
... Boy	120	49%			
Education	216				
... No University	67	31%			
... University	149	69%			
Reading Motivation (Index)	3.2	0.78	239	1	4
Language in the household	246				
... mixed,foreign	124	50%			
... native	122	50%			
Usage of Digital Media (Index)	2.7	1	235	1	5

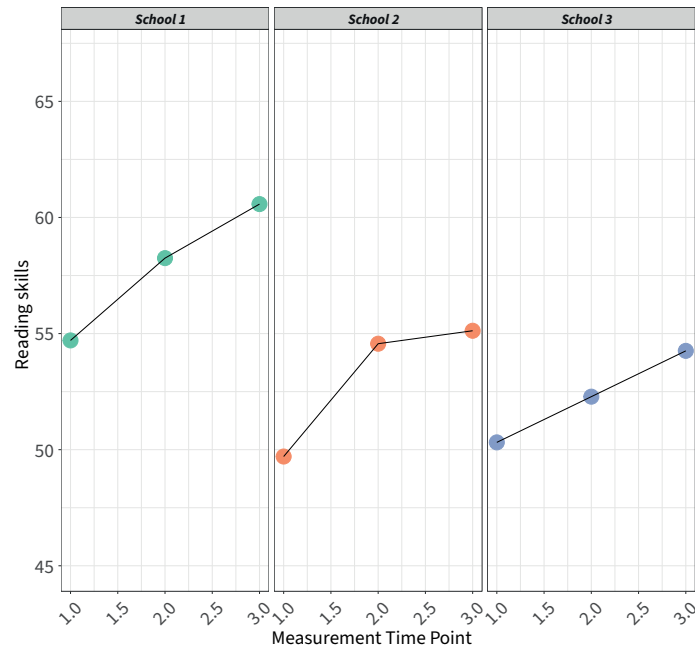
Table 1: Descriptives, MTP 1. Source: Digital Equity project, own calculations. For metric variables, the columns *Mean* and *Sd* each contain the mean and the standard deviation, for categorical variables *N* and the corresponding percentage values; no minimum or maximum is output here.

11. Results

Figure 1a shows the development of average reading ability (y-axis) per class in the different schools. The points represent the average value per class per measurement point, with blue and green points marking the type of intervention, which took place between the first and second measurement points. As mentioned above, only analogue interventions were conducted in School 3. Figure 1b shows the development of average reading ability per school, making clear that developments between schools differ significantly, both in terms of average starting level and increase. This heterogeneous development is represented in our modeling by the term u_{ts} , in which we separately model each measurement point in each school.



(a) Development of reading skills per class.



(b) Development of reading skills per school.

Fig. 1: Development of reading skills per class and school. Source: Digital Equity project, own calculations. The figure shows the development of reading ability within classes (1a) and within schools (1b) over three measurement time points.

Table 2 shows the results of the first modeling step as a linear multilevel model, with the columns containing individual modeling steps toward the full model in column 7. Model 1 shows the effects of intervention without control variables, but with u_{tsj} (Number of Groups: MTP:School) and v_{itj} (IDtotal). This shows an almost significantly positive effect of analogue intervention on reading ability, and a small negative non-significant effect of digital intervention. Control variables gender, parental education, reading motivation, household language, and media use are successively added to the model. This reveals a negative barely significant effect of gender, with boys scoring almost 2 points lower (Model 2). High parental education correlates with almost 3 points higher reading ability (Model 3). The reading motivation index shows the largest effect, correlating with significantly higher reading ability (Model 4). Household language plays only a small, non-significant role (Model 5). More frequent digital media use correlates with lower reading ability (Model 6). The interventions remain non-significant in models 2–4; only when controlling for household language and digital media use does the analogue intervention show a barely significant positive effect. In the overall model (Model 7), there is no significant effect of either analogue or digital intervention on changes in reading ability, however, the analogue intervention always tends to have a more positive influence.

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
(Intercept)	54.36 (1.24)***	55.29 (1.34)***	53.24 (1.47)***	46.47 (2.52)***	54.58 (1.37)***	57.26 (1.94)***	47.99 (3.16)***
Intervention: Analogue	0.94 (0.59)	0.93 (0.59)	0.92 (0.63)	0.88 (0.59)	0.94 (0.59)	1.11 (0.59) [†]	1.00 (0.63)
Intervention: Digital	-0.58 (0.63)	-0.62 (0.63)	-0.33 (0.66)	-0.62 (0.63)	-0.57 (0.63)	-0.35 (0.63)	-0.28 (0.67)
Gender: Boy (Ref.: Girl)		-1.99 (1.11) [†]					-2.23 (1.12)*
Education (Parents have at least one university degree)			2.83 (1.21)*				3.53 (1.20)**
Reading Motivation (Index)				2.50 (0.69)***			2.33 (0.70)***
Language HH: Mixed or Other (Ref.: German)					-0.44 (1.12)		1.03 (1.11)
Usage of Digital Media (Index)						-1.07 (0.54)*	-0.79 (0.53)
AIC	3902.92	3899.65	3426.05	3840.44	3902.70	3782.59	3318.66
BIC	3929.69	3930.88	3456.40	3871.58	3933.93	3813.62	3366.09
Log Likelihood	-1945.46	-1942.83	-1706.02	-1913.22	-1944.35	-1884.30	-1648.33
Num. obs.	640	640	565	632	640	622	551
Num. groups: IDtotal	215	215	190	211	215	208	184
Num. groups: MTP:School	9	9	9	9	9	9	9
Var: IDtotal (Intercept)	62.78	62.11	56.27	59.68	63.04	62.17	50.93
Var: MTP:School (Intercept)	10.31	10.31	9.79	10.67	10.33	10.13	9.46
Var: Residual	8.64	8.64	8.61	8.61	8.64	8.48	8.57

Table 2: Linear mixed effects models for interventions on reading skills. Source: Digital Equity project, own calculations.

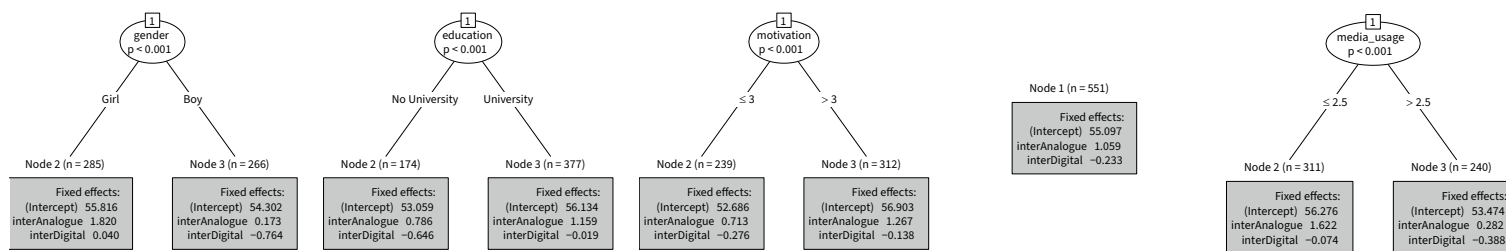


Fig. 2: Recursive partitioning by single control variables. Source: Digital Equity project, own calculations. The figure shows the results of recursive partitioning for the respective variables. Only one splitting variable was ever used for partitioning at a time.

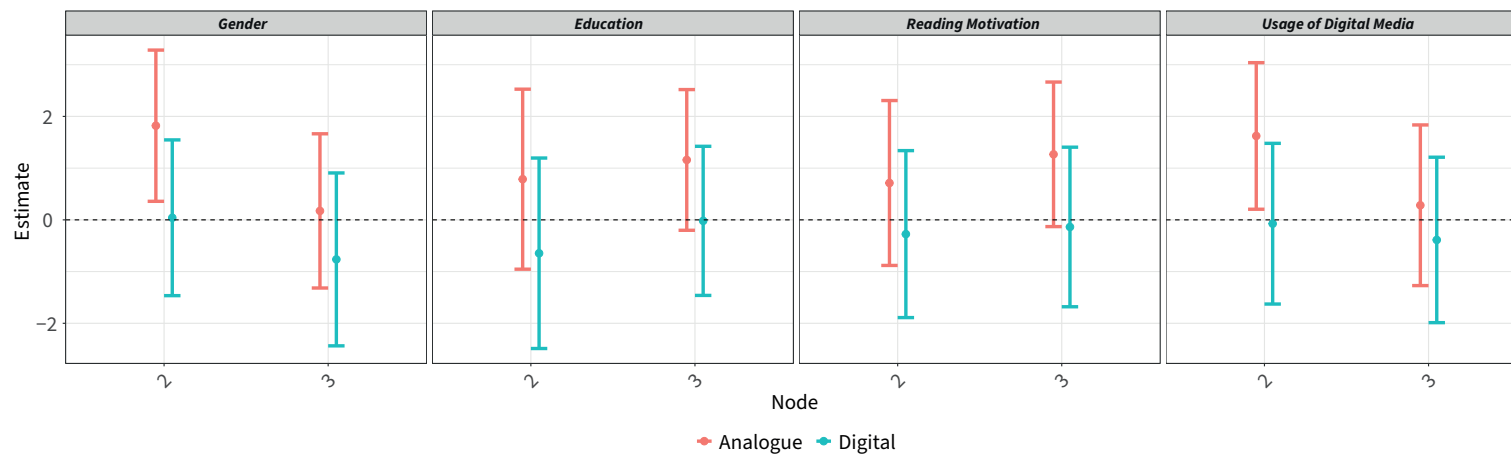


Fig. 3: Recursive partitioning by single control variables: Effect plot. Source: Digital Equity project, own calculations. The effect sizes shown at x-axis labels 2 and 3 are derived from nodes 2 and 3 in Fig. 2a, 2b, 2c, and 2e (own calculations).

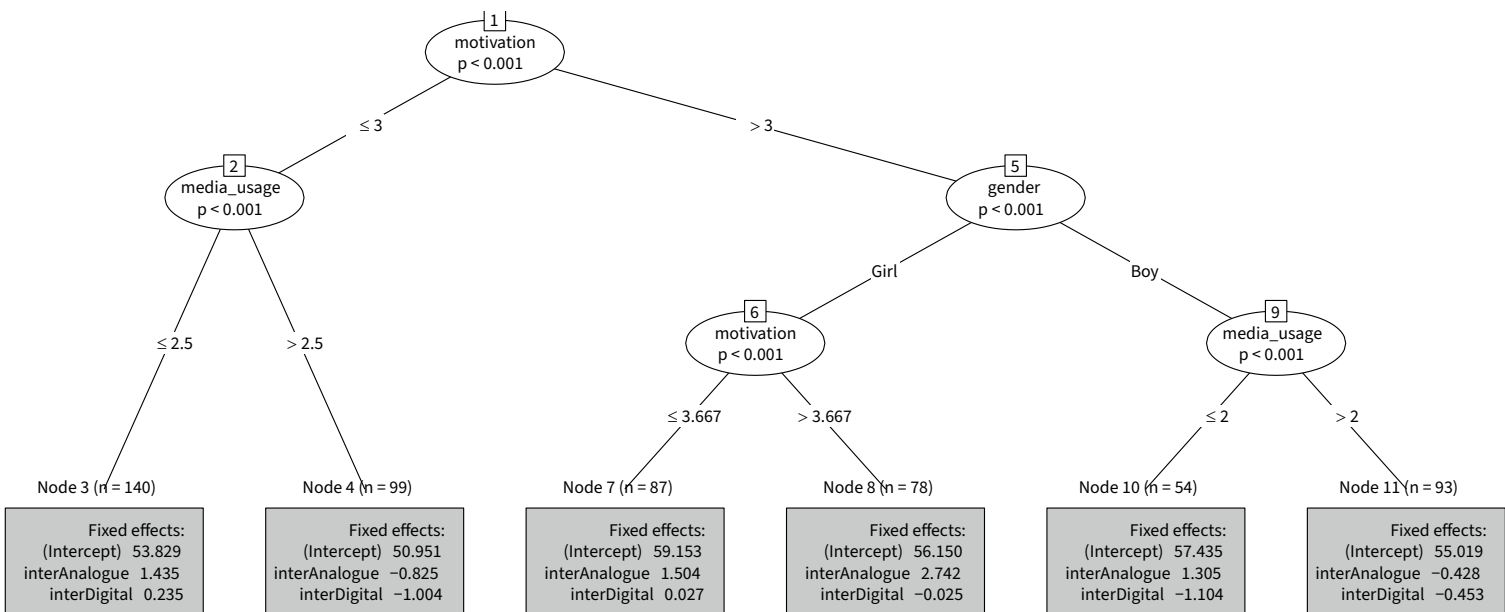


Fig. 4: Recursive partitioning by all control variables. Source: Digital Equity project, own calculations. Splitting variables are gender, education, reading motivation, language in the household, usage of digital media.

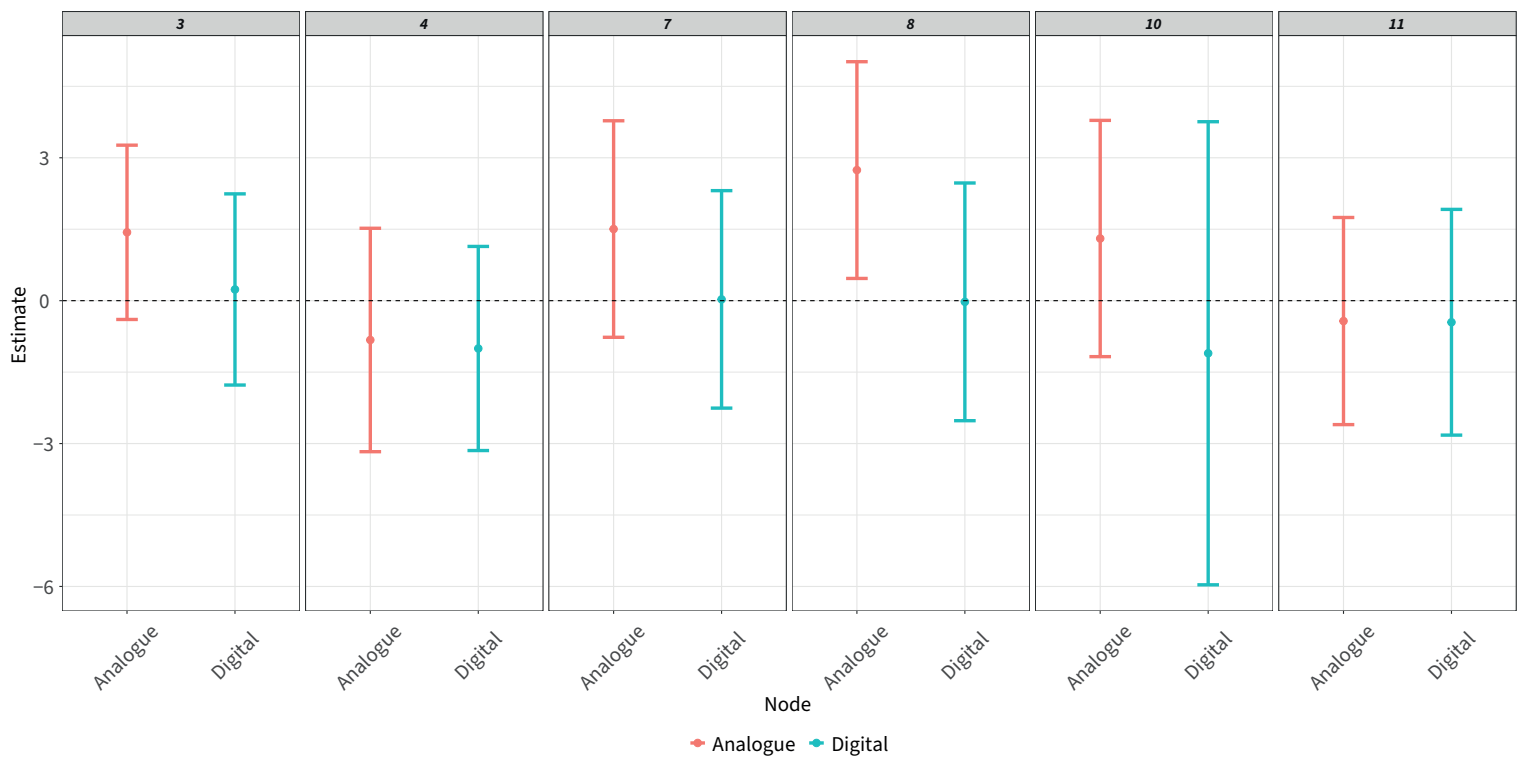


Fig. 5: Recursive partitioning by all control variables: Effect plot. Source: Digital Equity project, own calculations. Effect sizes are from Endnotes from Fig. 4.

In a further step, recursive partitioning was used to examine the extent to which subgroups can be distinguished based on control variables where the relationship between reading ability and intervention is maximal. For this, control variables were first used individually as splitting variables. Fig. 2 shows the results. Fig. 2a shows 3 nodes (splitting and endpoints) with a split by gender variable. Node 1 shows the separation variable and significance of the separation, indicating that the effects differ highly significantly by gender. The left branch leads to results for girls, the right to those for boys. For categorical variables, the branches show the expression; for metric variables, a cut-off value is given. The end node shows the group-specific fixed effects for the intervention's influence for girls, appropriately controlled for u_{tsj} and v_{tj} . This shows that the effect of analogue intervention for girls is 1.82, for digital only 0.04. For boys, analogue intervention has only a very small effect of 0.17, while digital intervention has a negative effect (-0.76) on reading ability development. Possible splits by education (2b), reading motivation (2c), and media use (2e) also lead to significantly different effects, but household language (2d) does not.

Fig. 3 provides a graphical overview of the significant effect differences from Fig. 2, whereby the x-axis shows the end nodes 2 and 3 and the y-axis shows the effect strength of the respective effects in the nodes, the zero line is shown as a horizontal dotted line. The effects are shown with 95 % confidence intervals, the red bar represents the effect of the analogue intervention and the turquoise bar the effect of the digital intervention. The left red bar (in Node 2) in the Gender sub-graph shows the effect 1.82 from Node 2 in Fig. 2a, as the confidence intervals do not touch the 0 line, the effect is significantly different from 0. Fig. 3 clearly shows that the analogue intervention tended to have a positive effect in all groups, while the digital intervention had no effect or tended to have a negative effect. Significant effects are only found for gender and media use for the analogue intervention, both in node 2. Girls and children who have an index value of up to 2.5 on the media use scale, i. e., who tend to consume little media, benefit significantly from the analogue intervention. The effect of the analogue intervention is also almost significantly positive for children whose parents have a university degree and for children whose reading motivation is greater than 3.

Figure 4 shows the full tree model, in which all variables from Model 7 in Table 1 are used as splitting variables. The first node here is a split according to the motivation variable, followed by media use (left) and gender (right). The branch with gender is also split again into motivation and media use. The variables in parental education and language in the household do not occur and are therefore less relevant for effect differences. Figure 5 again shows the effects including confidence intervals in the endnodes from Fig. 4, whereby the number of the node is included in the header of the individual graphs. Here, only node 8 shows a significant positive effect (2.742) of the analogue intervention. If one follows the path to node 8 in Fig. 4, it can be seen that this group consists of girls with a motivation of over 3,667. The analogue intervention also tends

to be more positive for less motivated children with low media use (Node 3), girls with a motivation >3 , but less than 3.667 (Node 7) and motivated boys with very low media use (less than or equal to 2, Node 10), but these also tend to be negatively influenced by the digital intervention, as do the unmotivated children with high media use in Node 4. Here, the analogue intervention also tends to have negative consequences.

12. Discussion

Our analysis shows that class-wide reading interventions yield heterogeneous effects across different student groups. The most notable finding emerged at the intersection of multiple student characteristics. Only highly motivated girls showed statistically significant benefits from the analogue intervention.

We also observed moderate positive effects from the analogue intervention for other groups. These included low-motivated children with minimal media usage, moderately motivated girls, and motivated boys with low media consumption. However, these effects did not reach statistical significance. This pattern suggests that reading interventions are deeply intertwined with individual student characteristics. They are not uniformly effective across the classroom. A particularly surprising finding emerged regarding digital media usage patterns. Contrary to our hypotheses, frequent digital media users showed negative responses to digital interventions. This was especially true when combined with low motivation. This counterintuitive result challenges common assumptions about digital natives and educational technology integration. It suggests that familiarity with digital media may not translate directly into effective educational engagement through digital media. However, none of these results are significant and should at best be interpreted as trends.

Our findings partially align with existing research demonstrating slightly better comprehension outcomes for analogue reading approaches (Delgado et al. 2018; Sidi et al. 2017). Delgado et al. (2018) highlighted the advantages of print-based reading methods, although only for non-fiction texts. They found no differences between print and digital texts when children read fictional texts and had ample time for reading. Similarly, our study shows no significant overall differences between analogue and digital interventions for the majority of the population, only a tendency that analogue interventions tend to have a more positive effect. However, we identified one specific subgroup where intervention effects emerged: highly motivated girls are the only group that showed a statistically significant benefit from the analogue intervention, while also demonstrating a positive but non-significant effect from the digital intervention. Importantly, while the analogue effect was the only one to reach statistical significance (confidence interval does not cross zero), the two intervention effects do not differ significantly from each other, as evidenced by the overlapping confidence intervals in Figure 5.

Further, our results reinforce prior research on the crucial roles of gender (McElvany et al. 2023; McElvany and Schwabe 2019) and motivation (Pfaff-Rüdiger 2011; Schwabe et al. 2021) in reading skill acquisition, and extend these findings in an important way. Even analogue interventions significantly benefit only a narrow demographic – specifically, highly motivated female students who can effectively engage with complex, multi-phase reading tasks.

These patterns can be understood through several theoretical lenses. Our findings align with Dalhaus' (2011) concept of «Individual Educational Knowledge» and the gaps between students' life-world knowledge and academic requirements. The differential effectiveness of our interventions across student groups suggests that meaning gaps persist even in innovative teaching approaches. The strong performance of highly motivated girls in analogue interventions can be understood through Bremer and Lange-Vester's (2015) framework. This framework focuses on power and dominance effects in educational settings. These students may possess what Kramer and Helsper (2010) term the «implicit habitus» expected by schools. This allows them to better leverage the intervention's collaborative and creative elements.

The limited success of digital interventions among frequent media users is particularly noteworthy. This may reflect what Bourdieu describes as misalignment between students' familial habitus and school expectations, as frequent media users often engage with digital technologies primarily for leisure activities like gaming and social networking rather than educational purposes (van Deursen and van Dijk 2014; OECD 2019), potentially creating a mismatch between their informal digital practices and the academic requirements of digital learning interventions. Our findings extend Cook, Pachler, and Bachmair's (2013) argument about acknowledging students' prior knowledge. While our interventions aimed to validate and build upon students' diverse experiences, the results suggest that this approach alone may not suffice. Future interventions need to go beyond merely acknowledging prior knowledge and must specifically adapt teaching and learning settings to both individual learning conditions and academic requirements. Our hypothesis that multimodal texts would bridge diverse learning needs and reduce educational gaps was only partially supported by our findings, as our results reveal complex interactions. They emphasize the necessity for targeted, group-specific interventions. Whether children benefit from analogue and digital interventions in reading depends on multiple factors. These include their social background, their gender, their media usage, and their reading motivation. Only by examining these interrelated characteristics can we explain the interventions' effects. We thus suggest a fundamental reconsideration of how reading interventions are designed and implemented. Particular attention must be paid to the complex interplay between individual student characteristics, their prior knowledge, and the specific demands of academic reading tasks.

While situated within the German education system, the implications of this study extend well beyond national borders. International evidence consistently confirms that digital reading formats, particularly for informational or expository content, pose specific challenges for comprehension and metacognitive regulation (Clinton 2019; Delgado et al. 2018). Our findings support this view, showing that digital interventions may even exacerbate existing disparities when applied uniformly across heterogeneous learner groups. This concern is heightened by recent ICILS 2023 data, which document a sharp rise in the number of German students from low-cultural capital households with only minimal digital competencies. Such patterns mirror global trends wherein rapid technological innovation has often failed to close equity gaps in educational outcomes.

Overall, our findings align with recent international evidence that highlights the heterogeneous effects of digital learning tools on student outcomes, particularly among younger learners. For example, results from ICILS 2023 and comparable multilevel analyses, e.g. Fraillon et al. (2025), confirm that digital reading performance is shaped by factors such as motivation, home environment, and prior media exposure. By identifying subgroup-specific patterns within a German primary-school context, our study contributes to this growing global discourse and emphasizes the need for localized yet internationally connected research.

In contributing to this international discourse, our study emphasizes that integrating technology into instruction is not sufficient unless accompanied by pedagogical models that adapt to students' diverse needs. Effective literacy instruction in digital societies must be both inclusive and data-informed, capable of supporting deep comprehension and reflective engagement across formats. This requires moving beyond the analogue/digital dichotomy and toward flexible, student-responsive strategies that leverage the strengths of each medium to promote equitable learning for all.

13. Limitations

Several limitations warrant consideration. The cluster-level assignment rather than individual randomization constrained generalizability and introduced potential systematic differences between groups. While baseline equivalence analysis revealed no significant differences (see Table A1), the cluster design creates potential confounding that individual randomization would better control. Hence, despite our pre-post panel design, causal claims remain limited. Our modeling approach controls for individual start levels and trajectories but cannot control for class-level characteristics since treatment was implemented at class level. The final sample of 15 classes and 184 participants (Model 7, Table 2) limited our ability to detect smaller effects. Analyses in our online appendix (<https://www.medienpaed.com/article/view/2037/1613>) indicate potential positive effects for digital interventions in some subgroups with larger samples, for example in less motivated children of parents with university degrees and low media use (Figure

A1, node 6), though these effects were not significant. Future research with larger samples may be better positioned to detect these potentially meaningful subgroup effects.

School-level characteristics influenced outcomes, as evidenced by different baseline levels and trajectories (Figure 1b), particularly in School 3 which only implemented analogue interventions due to limited infrastructure. Variable operationalization was simplified due to sample constraints, and analyses remained susceptible to outlier influence despite removing influential cases.

The exploratory recursive partitioning analyses require cautious interpretation. These data-driven algorithms increase risk of capitalizing on chance findings and remain susceptible to unmeasured confounding within subgroups. Limited sample sizes within terminal nodes reduce stability of effect estimates. While bootstrap analysis confirmed consistency of key factors across variations, significant effects represent associations rather than causal relationships. These limitations indicate our findings should be viewed as hypothesis-generating rather than confirmatory evidence.

14. Conclusion

These findings point toward several promising future research directions. Researchers should investigate more granular intervention designs targeting specific student profiles and examine the mechanisms underlying the negative digital intervention effects among frequent media users. Additionally, developing adaptive intervention strategies that account for individual student characteristics would be valuable, as would larger-scale studies with individual-level randomization to confirm these findings.

Our results have significant implications for educational practice. First, following Dalhaus' (2011) framework, educators should move beyond simple digital/analogue dichotomies when designing reading interventions and instead first assess the specific character of students' informal knowledge and educational experiences. This assessment should include evaluating the frequency as well as the quality of students' digital media use, understanding students' existing reading practices across different media, and identifying potential barriers in translating informal competencies to academic contexts. Our findings suggest a shift from universal approaches toward differentiated reading intervention strategies. When implementing digital interventions, careful consideration of student characteristics is crucial. Second, building and maintaining reading motivation appears to be a prerequisite for intervention success. Third, educators should be aware that collaborative and creative teaching and learning settings, even with analogous features such as reading in print books, are demanding and tend to benefit students with high academic learning prerequisites.

Our findings point to the value of differentiating instructional approaches not only by learner motivation and gender but also by media use behaviour. Tailoring interventions to media profiles could enhance their effectiveness and reduce the risk of overload or disengagement among heavy media users.

In conclusion, while our findings challenge the feasibility of universal classroom interventions, they provide valuable insights for developing more targeted approaches to reading instruction. The complex interplay between student characteristics and intervention effectiveness underscores the need for nuanced, differentiated approaches to reading instruction. Future research and practice should focus on developing and implementing interventions that account for these individual differences, while at the same time aiming to support students who currently derive limited benefit from existing approaches.

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