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ORIGINAL ARTICLE

The use of blended learning to promote learner-centered pedagogy in elementary math classrooms

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Abstract
Teaching and learning of foundational math have emerged as concerns in India, and might be connected with the problems of large classroom sizes and inappropriate curriculum resources. To address these problems of practice, ABC School explored the use of blended learning in three Grade 2 mathematics classrooms ($n = 108$), while a control group of three Grade 2 classrooms ($n = 113$) received traditional instruction and curricular resources. A quasi-experimental mixed-methods design was used to determine the differences in teaching, student engagement, and learning after eight months. Standardized test scores showed a significantly higher increase in the performance of the treatment group compared to the control group. Also, the treatment group experienced higher levels of learner-centered pedagogy, measured in terms of the extent of differentiated instruction, timely and precise feedback, and student engagement. This study contributes to the small pool of international experimental studies on blended learning in elementary grade classrooms, and supports a growing belief among researchers that the approach holds promise for school reform in developing countries.

Keywords Elementary mathematics instruction · Blended learning · Learner-centered pedagogy

1 Introduction

There has been a persistent concern in India regarding student achievement in math, with estimates showing from one-third to 50% of elementary students performing below proficiency on simple grade level tasks (ASER, 2005, 2019; Rajagopalan & Agnihotri, 2014). Sub-optimal pedagogy or classroom teaching quality has been identified as a driver of this poor outcome (Ministry of Human Resource Development, 2018; Probe Team, 1999; Singh

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& Sarkar, 2012). Classrooms in India continue to reflect teacher-centered, lecture-driven, rote learning-related activities that do not engage students as active learners, in spite of repeated appeals by national reform policy to abandon such practices and instead adopt *learner-centered pedagogy* (Dhawan, 2005; Kumar, 2005; Ministry of Human Resource Development Department of School Education Literacy (2011); Ministry of Human Resource Development, 2020; National Council for Educational Research & Training, 2005; National Council for Teacher Education, 2009; Probe Team, 1999; Singh & Sarkar, 2012). This gap between policy recommendations and the actual practice of learner-centered pedagogy in classrooms has been experienced in several developing countries, and is driven by complex systemic and sociocultural factors (Cheng & Ding, 2021; O'Sullivan, 2004; Otara et al., 2019; Schweisfurth, 2015; Sivri & Sahin, 2021). One key issue with learner-centered pedagogy is that it lacks a precise definition in national policy and international literature (Bremner, 2021; Schweisfurth, 2015; van de Kuilen et al., 2020). In this study, we define learner-centered pedagogy as one that enables students to be active protagonists in their own learning process, reflected at the very minimum in higher student engagement, differentiated instruction, and precise and timely feedback in the classroom (An & Mindrila, 2020; Cheng & Ding, 2021; O'Sullivan, 2004; Otara et al., 2019; Schweisfurth, 2013, 2015).

Two of the many factors in India that are at odds with learner-centered pedagogy are incompatible curricular resources and large classroom sizes (Brinkmann, 2018). Firstly, textbooks prescribed by educational boards assume a one-size-fits-all approach to teaching and learning. Seat time is considered synonymous with learning, and all students in a classroom are introduced to new content regardless of whether they have demonstrated any mastery of prior content. The syllabus is vast, and teachers are forced to keep a steady and brisk pace in order to complete all the topics prescribed for the year. India has been too focused on advanced content rather than building foundational skills in a developmentally appropriate manner (Banerjee & Duflo, 2012; Glewwe et al., 2009; Pritchett & Beatty, 2012). Secondly, it is practically impossible for teachers to conduct formative assessments that check for understanding on an ongoing basis, differentiate their instruction, and provide targeted feedback to learners given the large number of students per class and the heavy teaching loads per week that educators are expected to deliver. Primary classrooms can be found housing up to 60 or more students (Hegde & Cassidy, 2009; "India Improves Student-classroom," 2018; India Today Web Desk, 2017), placing India in the bottom quartile of ideal teacher-student ratios in the world (OECD, 2017; UNESCO Institute for Statistics, 2017). However, more recently, the effective use of educational technologies has been proposed as an intervention with high potential to address some of the problems in the Indian schooling context (Kundu, 2018; Ministry of Human Resource Development, 2020). Inspired by this idea, ABC School—a mid-tiered, private K-10 school in Mumbai, India—implemented a station-rotation model of blended learning (BL) mathematics program in three of its six Grade 2 classrooms. This study describes the outcomes of the intervention.

2 Literature review

There is ambiguity over the precise definition of BL (Hrastinski, 2019; Stein & Graham, 2020). However, at its core, BL implies a mixture of learning and teaching, through two types of engagements—computer-mediated online learning and traditional face-to-face learning (Dziuban et al., 2018; Garrison & Kanuka, 2004; Graham, 2006; Staker & Horn, 2012; Vallee et al., 2020). It is a hybrid innovation where digital instruction complements traditional classroom instruction (Christensen et al., 2013; Hrastinski, 2019; Smith & Hill, 2019), allowing students to move towards learning goals through engagement with content that is thoughtfully integrated across online platforms and face-to-face engagements (Christensen et al., 2013; Pane et al., 2017; Patrick et al., 2013; Stein & Graham, 2020). Typically, BL also offers students a greater degree of flexibility and agency in their learning by giving them control over variables that were previously fixed by the teacher, including the path and pace of progression through the curriculum (Albiladi & Alshareef, 2019; Bouilheres et al., 2020; Christensen et al., 2013; Senffner & Kepler, 2015).

2.1 Types of BL

BL can take on many forms. Staker and Horn (2012) proposed four major models (Fig. 1). First, the Enriched-Virtual model entails that within each course studied on a physical campus there must also be some elements to be completed online. Second, the Self-Blend model entails that students study most courses on a physical campus but take a few courses of their choice entirely online. Third, the Flex model entails that a program's content be delivered mostly online with only need-based face-to-face support, and students progress through an instructional plan and schedule that is individually customized. Finally, the rotation model entails that within a specific course or even lesson students are made to move between modalities like group work, mini lectures, pencil-paper assignments and such, with at least one modality necessarily involving online learning. The rotation model can be further categorized into four models—individual rotation, flipped classroom, lab rotation, and station rotation. Each of these is differentiated by either the location or the schedule of rotation. For example, in the station-rotation model, students move during a lesson between instruction through different modalities like teacher-led large group explicit instruction, small group work, paper–pencil individual work, and others, where at least one modality is online learning. The classroom space is divided into separate stations—each

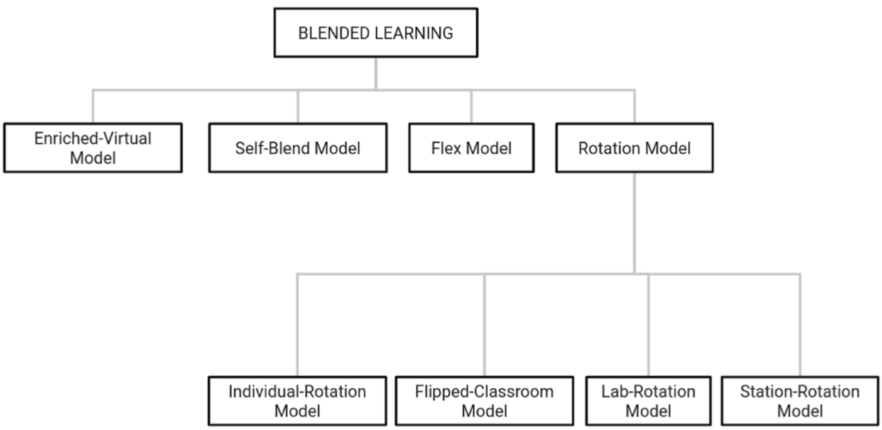

Fig. 1 Four models of blended learning (Staker & Horn, 2012, p. 8)

station dedicated to a learning modality, and students move between modalities based on teacher discretion or a fixed schedule (Staker & Horn, 2012).

2.2 Effects of BL

The most seminal meta-studies on the effects of online learning were published by the US Department of Education (Means et al., 2009, 2013) and found that BL was more effective for student learning than purely face-to-face instruction. More recent studies echo the same finding across multiple contexts including higher secondary physics classes (Sivakumar & Selvakumar, 2019), Grades K-5 reading (Macaruso et al., 2020; Prescott et al., 2018), Grade 7 math (Lin et al., 2016), elementary STEM subjects (Seage & Türegün, 2020), and Grade 7 history (Ch & Saha, 2019). While these particular studies might not have clearly established the mediating factors that influenced improved student learning, there is literature that points to the positive influence that BL has on differentiated instruction (Brodersen & Melluzzo, 2017; Fazal et al., 2020; Pane et al., 2015; Stein & Graham, 2020), effective feedback practices (Horn & Staker, 2011; Murphy et al., 2014; Stein & Graham, 2020), and student engagement (Kundu, 2018; Kundu et al., 2020; Lin et al., 2016; Stein & Graham, 2020). These are variables associated with effective teaching and student learning as per evidence-based classroom instructional frameworks like the Framework for Teaching (Danielson, 2013) which is aligned with the same constructivist ideology (Piaget, 1973; Vygotsky, 1978) that inspires the Indian National Curriculum Framework (National Council of Education Research and Training, 2005) and learner-centered pedagogy (van de Kuilen et al., 2020).

This study compares the teaching practices and learning outcomes experienced by three sections of Grade 2 math students that received a BL curriculum versus three sections of Grade 2 math students that received traditional classroom instruction, at ABC School. Our first hypothesis was that students in the treatment group would experience more learner-centered pedagogy or teaching practices in terms of differentiated instruction, precise and timely feedback, and student engagement, as found in earlier research. And, our second hypothesis was that students in the treatment group would perform significantly higher than students in the group receiving traditional instruction, as shown in earlier research.

3 Methodology

The study applied a quantitative dominant quasi-experimental explanatory mixed-methods design (Creswell & Plano Clark, 2017) to assess the program's outcomes. Such a design entailed the collection of both—quantitative and qualitative data, allowing for deeper insights that would be impossible if only one type of data were collected (Creswell & Plano Clark, 2017; Johnson & Onwuegbuzie, 2004; Onwuegbuzie & Leech, 2006; Tashakkori & Teddlie, 2003).

3.1 Sampling and participants

A mixed-methods sampling strategy was used, entailing a combination of probability and purposive sampling techniques (Etikan & Babtope, 2019; Teddlie & Yu, 2007).

First, six classrooms of Grade 2 were chosen based on practical, timetable related constraints. The school had already identified two teachers to instruct three sections of Grade 2 each. The researchers relied on simple random sampling (Etikan & Babtope, 2019; Teddlie & Yu, 2007) to assign an equal number of sections to the two teachers and decide which of the two teachers and their sections would comprise the control group and treatment group.

3.1.1 Students

A total of 108 students were part of the treatment group, of which 58.3% were boys and 41.7% were girls. And, 113 students were part of the control group, of which 56.6% were boys and 43.4% were girls. Students in both groups were studying in Grade 2. Six students from each group participated in focus group interviews in the first month of implementation and after the implementation of BL. Participants were chosen using a cluster sampling method (Etikan & Babtope, 2019; Teddlie & Yu, 2007). First, the baseline standardized math scores using EasyCBM tests—explained further in the measures and instrumentation section—were studied for the control group and treatment group students. Then, students from each group were clustered into three bands—top 25% scorers, bottom 25% scorers, and mid 50% scorers. Finally, two students were randomly selected from each band and group.

3.1.2 Teachers

Teacher A and Teacher B were both female and had five years of prior teaching experience. Teacher B possessed a Bachelor's Degree in Education, with a focus on Economics, and English. Teacher A possessed a lower qualification—a diploma in education. However, both teachers possessed the minimum educational certification required to teach Grade 2 level Math, as per the statutory prescriptions of the Indian School Certificate Examinations (ICSE) which ABC School was affiliated with. Teacher A implemented BL, while Teacher B used the same curricular resources that all other grades in the school had been using for the past few years.

3.2 Intervention design

The treatment and control groups proceeded through the same sequence of math topics through the study period. The school leaders and researchers mapped out the content for both groups at the outset of the academic year in a way to ensure that they were aligned with the prescriptions of the ICSE Board which the school was affiliated with. Also, both treatment and control groups at ABC School were allotted math periods of 76 min per class for four days a week. However, the treatment group used Zearn Math online curricular resources, which included an online *adaptive digital content* platform that engaged students in independent practice with automated feedback and automated matching of task difficulty to ensure just right challenges based on the child's demonstrated mastery. The control group continued using the traditional math curriculum that was textbook-based and already being implemented for years at ABC School.

The treatment group employed a station-rotation BL model. Every lesson started with 15 min of whole-group instruction to engage students in fluency activities, collaborative problem solving, mathematical sense making, and activation of prior knowledge. Students would then be split into two groups—one group of 20 students would move to the front of the classroom to receive small group targeted instruction by the teacher, while the other group of 20 students would move to the other end of the class to engage in independent digital lessons (IDL) on the Zearn online platform. The groups would switch after 30 min to ensure all students receive small group instruction and IDL time daily. Real-time data regarding student progress, pace, and struggles were available to the treatment group teacher via the online teacher account. The data allowed her to reflect on how individual students were responding to instructional strategies. She could then purposefully group and regroup students based on their needs. For every four lessons that focused on delivering the core content (Core Days), a fifth lesson was structured in a flexible manner where students received differentiated tasks based on their difficulties and progress with Zearn digital lessons (Flex Days).

The treatment group teacher was provided with a mobile laptop cart that stored 20 laptops, 20 headphones, and one Internet router to provide WiFi access to the laptops. She would take the cart to all of her lessons across the three treatment group classrooms. Further, she accessed free-of-cost training material, teaching resources and aids for whole-group and small group instruction, including printouts of lesson plans, exit tickets, and various student assessments. The teacher was also provided with a personal computer and Internet facilities during school hours to ensure access to the Zearn online platform.

3.3 Measures and instrumentation

3.3.1 Learner-centered pedagogy

With regard to measuring learner-centered pedagogy, little clarity is available on what exactly such practice entails. While the National Curriculum Framework 2005, National Curriculum Framework for Teacher Education 2009, and the National Education Policy 2020, all espouse learner-centered or student-centered pedagogy as an ideal, none of the documents attempt to define the construct in precise and measurable terms. This is an issue with learner-centered education internationally too—there is no precise universal definition available (Bremner, 2021; Schweisfurth, 2015; van de Kuilen et al., 2020). However, there is consensus over the core idea that learner-centered pedagogy implies practices that starkly contrast those characterized by traditional teacher-centered pedagogy, and instead make students active protagonists in their learning process (Cheng & Ding, 2021; O'Sullivan, 2004; Otara et al., 2019; Schweisfurth, 2013, 2015). In an attempt to provide some broad framework to the construct, Schweisfurth (2013) outlined a list of minimum standards for learner-centered pedagogy. Three of the seven standards align with the findings from prior research on BL related to high student engagement, differentiated instruction, and effective assessment and feedback (Brodersen & Melluzzo, 2017; Fazal et al., 2020; Kundu et al., 2020; Lin et al., 2016; Murphy et al., 2014; Pane et al., 2015; Stein & Graham, 2020). Considering this, our study measured learner-centered pedagogy in terms of the increase in *student engagement, differentiated instruction*, and *precise and timely feedback*.

Student engagement implies an outward manifestation of motivation (Skinner et al., 2009), and a display of behaviors that help learners generate the interest, focus, and attention required to build new knowledge or skills (Toshalis & Nakkula, 2012). It is not just being *busy* or *on-task* but instead being *intellectually active* and attentive, where learning activities are not merely *hands-on* but also *minds-on* (Danielson, 2013, p. 3). Theory and empirical studies have suggested that student engagement is a key determinant of student learning (Carini et al., 2006; Mayer, 1996; Schunk, 2012). With regard to differentiated instruction, it implies modification of either content, process, product, or affect, to appropriately match student readiness, interest, and learning profiles (Tomlinson, 2014; Watts-Taffe et al., 2012). It acknowledges the need to abandon the traditional one-size-fits-all approach to teaching which presumes that all students are in exactly the same place in their learning journeys and require exactly the same type of support to maximize their pace and depth of learning (Tomlinson, 2014). In this study, differentiation is related mainly to modifications in content and process. Differentiated instruction has been promoted in the literature as an effective strategy to foster inclusive teaching and higher student learning (Connor et al., 2011; Magableh & Abdullah, 2020; Tomlinson et al, 2003). Finally, precise and timely feedback implies providing students with specific guidance on how to improve—in a way that is certain, clear, and easy for students to understand and respond to (Shute, 2008). It "targets the specific stage a learner has reached and offers guidance the learner can immediately apply" (National Academies of Sciences, Engineering, & Medicine, 2018, p. 148). Literature reviews and meta-studies over decades have shown that such feedback is a key determinant of student performance (Hattie, 2008; National Academies of Sciences, Engineering, & Medicine, 2018).

Data for these measures were collected from focus groups with students and a personal interview of Teacher A. Also, a classroom observation tool (Supplementary Material S1) was developed and used by extracting indicators related to differentiated instruction, student engagement, and feedback, from the Framework for Teaching evaluation tool (Danielson, 2013). The Framework for Teaching tool was developed more than 25 years ago and has been continuously iterated over time based on empirical studies and theoretical research along with consultation with expert practitioners and researchers (Danielson, 1996, 2007). Classroom observations were conducted of one randomly selected section of the treatment group and control group, each observed four times, for 76 min each time by two researchers. The first two observations for each group took place within the first month of implementing BL, and the next two observations took place in the last month. The treatment group observations were scheduled in a manner that allowed researchers to observe one Core Day and Flex Day class each as part of every round of observations. The teachers were not informed beforehand. The interrater reliability for the classroom observation tool used in this study was established using a combination of methods. First, the researchers computed absolute percentage agreement by estimating the proportion of rubric descriptors that the two raters ticked or did not tick across all observations conducted. Agreement was assumed if both raters ticked a descriptor, implying that they observed that descriptor in practice in the classroom, and also if both of them did not tick a descriptor implying that they were in agreement about it not being demonstrated in the classroom being observed. The mean percentage agreement across all eight observations conducted by the two raters was 86.33%, indicating a high level of agreement (Graham et al., 2012). Despite its practical utility, absolute percentage agreement has come under critique as a standalone measure of reliability given its inability to account for chance agreement which leads to potentially inflated estimates of agreement (McHugh, 2012; Zhao et al., 2013). Hence, Kappa coefficients were also computed considering their widespread use for categorical data that involves two raters and ability to account for chance agreement (de Raadt et al., 2021; McHugh, 2012; Warrens, 2015). The mean Kappa coefficient across all eight observations conducted by the two raters was 0.65, indicating *substantial* reliability (McHugh, 2012). The detailed raw data sheets and findings for the reliability statistics presented above have been included in Supplementary Material S2.

3.3.2 Higher student performance

Student performance was measured using a curriculum-based measurement tool. Curriculum-based measurements monitor student progress towards grade-level proficiency in critical skills and content in a specific academic year, without being associated with a particular set of curricular resources (Anderson et al., 2010; Fuchs, 2017). Hence, such assessments are referred to as general outcome measures (Deno, 2003). This study administered EasyCBM—an online math test created by the University of Oregon—before, during and after BL implementation, to measure student learning. Three Grade 2 progress-monitoring tests from the entire battery of Easy CBM tests were used for this study. Cronbach's Alpha was computed to assess the internal consistency reliability of all three tests used in the study, i.e., pre-, mid- and post-pilot assessments. For all the measures and across both treatment and control groups, Cronbach's alpha ranged from 0.94 to 0.97, indicating strong reliability. For split-half reliability as well, coefficients were strong and ranged from 0.86 to 0.95.

3.4 Data collection and analysis

This study utilized a quasi-experimental mixed-methods design characterized by (i) a quantitative dominant method; (ii) use of both methods simultaneously; and (iii) mixing data from both methods for concluding findings (Creswell & Plano Clark, 2017). Quantitative data were collected from student performance on EasyCBM and classroom observations. Qualitative data were collected from student focus groups, Teacher A's personal interview, and descriptive notes from classroom observations. With regard to the classroom observation tool, items were listed under the rubric of unsatisfactory, basic, proficient, or distinguished teaching behavior. Items under the category of unsatisfactory were assigned 0 points, basic = 1 point, proficient = 2 points, and distinguished = 3 points. Three aspects of teaching were assessed by this tool—differentiated instruction, student engagement, and feedback. For each observation by each observer, the total tick marked items were collected for each aspect of teaching, and they were multiplied by their corresponding rubric weightage to provide a total score. For example, if Observer 1 tick marked three items under the unsatisfactory rubric under the aspect of differentiation, in addition to seven items under the basic rubric, one item under the proficient rubric, and zero items under the distinguished rubric, then the total score for Observer 1 for differentiation of instruction would be $(3 \times 0)+(7\times 1)+(1\times 2)+(0\times 3)=9$ points. The scores given by both observers were then averaged for each aspect of teaching and compared between the two groups and two periods of time.

Focus group and interview data were analyzed using NVivo coding (Miles et al., 2020). As such, the researchers relied on a priori codes based on three indicators of learner-centered pedagogy measured by the study—differentiated instruction, precise and timely feedback, and student engagement. The researchers first read through the corpus of data multiple times (Rossman & Rallis, 2017). Next, data were coded that aligned with the three indicators being measured. These codes were subsumed under the theme, "learner-centered pedagogy." The researchers discussed the codes and themes collectively, to ensure agreement and maximize the credibility of findings (Shenton, 2004).

EasyCBM scores for the treatment group and control group were examined for normality using measures of skewness (Sk), kurtosis (K), z-scores, and missing values. The baseline analysis for the CBM scores across the treatment and control conditions indicated that the residuals were nearly normally distributed using a threshold of $-1 < Sk > 1$ and $-1 < K > 1$ for skewness and kurtosis, to indicate normality (CBM: $Sk_{Control} = 0.07$, $Sk_{Treatment} = 0.22$; $K_{Control} = -0.40$, $K_{Treatment} = -0.83$). Further, there were no univariate outliers as indicated by z-scores. The mid-scores for CBM also did not show departures from normality across the treatment and control conditions. Values for skewness were well within acceptable limits with a slight departure for kurtosis in the treatment group (CBM: $Sk_{Control} = -0.22$, $Sk_{Treatment} = -0.27$, $K_{Control} = -0.64$, $K_{Treatment} = -1.04$). In addition, there were no univariate outliers. Finally, the end-line scores for CBM did not demonstrate departures from normality (CBM: $Sk_{Control} = -0.42$, $Sk_{Treatment} = -0.98$, $K_{Control} = -0.51$, $K_{Treatment} = 0.59$). The CBM scores were also examined for Homogeneity of Variance (HOV). This assumption was upheld by Levene's test of HOV (all $ps > 0.025$). To examine differences in the EasyCBM scores a two-factor split-plot ANCOVA examined (1) a Group Main Effect examining differences between the treatment group and control group, (2) a Time Main Effect examining differences between the time points, and (3) an interaction between time and group effects. Findings were examined using an alpha-level = 0.05. The effect size was used to examine the percentage of variation in the outcome that was attributed to group differences.

4 Results

4.1 Increased learner-centered pedagogy

Descriptive quantitative analysis showed a considerable positive association between the implementation of BL and increased learner-centered pedagogy (Fig. 2). The average

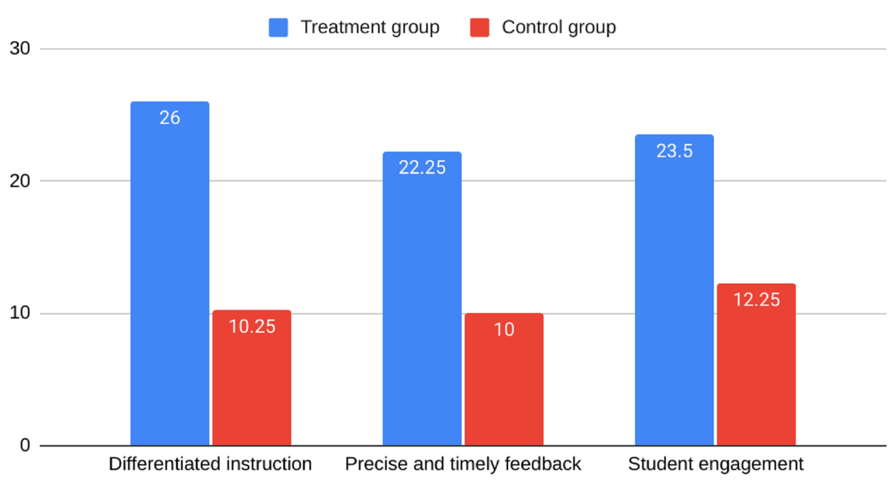

Fig. 2 Average scores on learner-centered pedagogy indicators across observations in first and last month of study

scores of two observers across four observations of each group showed that the treatment group teacher's performance on differentiated instruction was 154% higher than the control group, student engagement was 92% higher, and timely and precise feedback was 123% better.

4.1.1 Differentiated instruction

Observers gave the control group teacher an average of 10.25 points for differentiated instruction across their observations in the first and last month of the study (Fig. 2). The average score of the treatment group teacher was 26 points, over double that of the control group teacher. In her interview, Teacher A shared that Zearn data allowed her to track individual students' pace, progress, and struggles; and tailor Flex Days to meet their needs. Teacher A explained she would not have been able to collate and analyze such a large amount of student data manually while using the traditional curriculum, and that a structure like Flex Day would have been impossible to implement without the real-time student data made available daily on the Zearn online platform.

In their focus group, treatment group students explained that peers who fell behind in pace were assigned IDLs for homework to catch up. Students shared that those who finished faster could move forward within a lesson instead of waiting for the rest of the class. If they went too far ahead, then students were asked to help their peers catch up. Contrastingly, control group students shared that they had to wait for all their peers to finish before the class could move ahead. Anyone that fell behind used "free periods" during the school day to catch up.

4.1.2 Precise and timely feedback

Observers gave the control group teacher an average of 10 points for precise and timely feedback across their observations in the first and last month of the study (Fig. 2). The average score of the treatment group teacher was 22.25 points, over double that of the control group teacher's score. In the treatment group, one observer noted that students received "feedback via the app based on their progress, mistakes, and struggles" in real-time during IDLs. On the other hand, when the control group teacher walked around class to check students' books, she left her signature or a comment saying "not done" without any concrete feedback.

In the post-intervention focus group, students were asked what they did when experiencing difficulty with understanding something in class. Control group students shared that they could ask their teacher at any time and if any student had a doubt, the teacher would help. Treatment group students shared that they could start by asking their peers—at least two people sitting around them—followed by checking with their teacher. Further, they could access the online Zearn platform, "go to MyStuff, and revise the Tower of Power and Math Chat" or "rewind and watch" the explanation videos. Finally, during their IDLs, they solved questions independently and if something was incorrect, they were given two forms of immediate feedback—"let's do it together" or "go back to Math Chat." One student felt they had been "improving," which they knew because of teacher feedback and the "green star" they had received on their Zearn online profile. In her interview, Teacher A explained that students were retaught if they made mistakes, and the difficulty of questions only increased if the student demonstrated mastery of the concept in IDLs. She could also tailor feedback by looking at student performance data and used the completion tracker and gave stars as rewards.

4.1.3 Student engagement

Observers gave the control group teacher an average of 12.25 points for student engagement across their observations in the first and last month of the study (Fig. 2). The treatment group teacher's average score was 23.5 points—almost double the control group teacher's score. In the post-intervention focus groups, control group students shared that they enjoyed the teacher's explanations; however, typically only 10 to 12 students participated in a class of 40 students. Treatment group students expressed that they enjoyed the BL format more than the previous year's classes. They shared that class explanations helped students understand concepts "properly." They felt they had been "learning new things" in an "interesting" and "fun way." Although some students did not enjoy Math before, with BL it became their "favorite period." One student expressed that they had thought they were weak in Math but felt confident after learning through BL. Teacher A found that her students were engaged "all the time," more than students in her class in the previous year. In her interview, she explained that BL allowed her to do interesting activities that went beyond what she was able to do before. Observation data revealed that although students in the control group that finished earlier than their peers could practice in their workbooks, they talked instead and consequently disturbed peers.

4.2 Increased student learning

4.2.1 EasyCBM

A two-factor split-plot ANCOVA was performed to examine the extent to which the CBM scores statistically differed over time, differed across groups, and if an interaction existed when controlling for the baseline scores. Firstly, the findings revealed a statistically significant difference across the mid- and end-line scores when controlling for the baseline scores ($F_{1,218} = 37.70$, $p < 0.001$, adjusted$M_{mid} = 16.33$, adjusted$M_{end\text{-}line} = 17.59$). Secondly, there was a statistical difference between the control ($M_{Control} = 16.25$) and treatment ($M_{Treatment} = 17.67$) conditions ($F_{1,218} = 13.77$, $p < 0.001$). The effect size for this difference was measured by $\omega^2 = 0.042$. As such, 4.2% of the variance in the CBM scores is attributed to differences in the treatment group and control group. Thirdly, there was no statistically significant interaction found ($F_{1,218} = 1.68$, $p = 0.20$) (Table 1).

Effect size was also measured in terms of Cohen's d, given its widespread use in the evaluation of educational programs over the past few decades. There was no statistically significant difference found between the treatment and control groups at the baseline test

Table 1 Curriculum-based measurement descriptive statistics mean

	Control	Treatment
Baseline scores	13.84	13.65
Midline scores	15.49	17.17
End-line scores	17.01	18.16

Table 2 Percentile performance in treatment group (TG) and control group (CG)

Percentiles	Baseline scores (%)	Midline scores (%)	End-line scores (%)
Low percentile (0–30th)	CG: 35.40 TG: 41.67	CG: 40.71 TG: 26.85	CG: 51.33 TG: 37.04
Mid percentile (31st–60th)	CG: 36.28 TG: 25.93	CG: 30.97 TG: 25.93	CG: 24.78 TG: 28.70
High percentile (61st–99th)	CG: 28.32 TG: 32.41	CG: 28.32 TG: 47.22	CG: 23.89 TG: 34.26

($d=0.007$, $p=0.952$). However, the treatment group's mean posttest performance was significantly higher than that of the control group ($d=0.34$, $p<0.05$). The effect size can be considered as *large* (Kraft, 2020; Lipsey et al., 2012). With regard to the change in performance within each group over time, the effect size of growth in scores for the treatment group was $d=0.97$, while the growth in performance of the control group was only $d=0.68$.

The baseline test showed students in the treatment group scored lower on average and had a higher percentage of students in the lowest percentile category than in the control group (Table 2). However, in the end-line test, the percentage of students in the lowest percentile category increased in the control group and decreased in the treatment group. Also, the percentage of students scoring in the highest percentile category in the end-line test increased in the treatment group and decreased in the control group. The curriculum-based measurement scores of students in the treatment group increased substantially between baseline and midline tests, as compared to the mean score increase between the midline and end-line tests. Contrastingly, the growth rate in mean scores of the control group across all three tests was linear.

5 Discussion

Our first hypothesis was that students in the treatment group would experience more learner-centered pedagogy in terms of differentiated instruction, precise and timely feedback, and student engagement. This hypothesis was confirmed. Prior studies echo the finding that BL supports differentiated instruction (Brodersen & Melluzzo, 2017; Fazal et al., 2020; Pane et al., 2015; Stein & Graham, 2020) higher student engagement (Kundu et al., 2020; Lin et al., 2016; Stein & Graham, 2020), and effective feedback (Horn & Staker, 2011; Murphy et al., 2014; Stein & Graham, 2020). To begin with, Zearn allowed the teacher to administer checks for understanding more often in comparison to the teacher without technology. This is because teachers at the school under study would physically collect student notebooks and manually correct assessments and provide feedback on a weekly basis. This entailed correcting the work of more than 250 students, over multiple classes in the week since each teacher taught several grades of 40 children each. This made it impossible to administer ongoing formative assessments or checks for understanding more regularly. On the other hand, Zearn Math Administered CFUs on an ongoing basis because all the corrections and feedback were automated by the program. Further, the program provided opportunities for immediate and ongoing feedback to students in its various settings—large group, small group, and independent work. Large group instruction and discussions provided opportunities for student–teacher and student–student interactions, while small group instruction allowed for more targeted feedback from the teachers and peers. However, most critical and unique to the BL experience was the feedback that students received from the digital platform when students were doing their IDLs. The computer program would provide students with real-time feedback, and adjust the difficulty of the task and even offer remediation suggestions based on student performance. In this sense, IDL engagement was aligned with *competency based learning*, where students had to demonstrate mastery on their learning goals in order to go ahead and move on to the next goal instead of the traditional system of merely progressing through classes after a predetermined period of time regardless of learning (Patrick & Sturgis, 2015; Patrick et al., 2013; Schweder et al., 2019). Studies have shown that students in competency based learning classrooms achieved higher results and developed greater self-confidence than those in traditional classrooms (Adeyemo & Babajide, 2014; Anderson, 1994; Wambugu & Changeiywo, 2008).

The IDLs provided feedback and remediation for current and previous grade level tasks. Supplementary video content, visual representations and scaffolded digital manipulations were used to give students additional support to gain conceptual clarity precisely where each of them required it—based on their unique needs. Also, the teacher received real-time data on student engagement and performance on a daily basis that allowed her to adjust instructional supports and tasks as needed on Flex Day. The result was a highly differentiated learning experience for each student. Differentiated instruction is well aligned and connected with the idea of universal design for learning (Griful-Freixenet et al., 2020; Hall et al., 2003)—an approach to teaching that is focused on inclusion and learner-centered pedagogy (Griful-Freixenet et al., 2020; Rose & Gravel, 2012). Universal design for learning is based on research in neuroscience about the uniqueness of learning in an individual's brain (Hall et al., 2012). Its core principle is to present students with a multimodality of representations, and opportunities for action, expression and engagement (Griful-Freixenet et al., 2020; Rose & Gravel, 2012; Sailor, 2014). The BL program implemented at ABC School aligned with these key principles. Students participated in a range of learning experiences including whole-group teacher-led instruction, small group lessons, and independent work while doing their IDLs. During lessons, students engaged with learning tasks through a variety of modalities, including digital interfaces, concrete manipulatives, and also paper and pencil work. Such multimodal learning is known to promote learning more effectively and efficiently (Broadbent et al., 2018; Meredith & Stein, 1986; Stein & Stanford, 2008).

Given the customization of differentiated instruction and UDL demands, technology is an important tool that can be used to tailor versatile instructional material (Hall et al., 2012). However, technological tools can (a) merely substitute older practices without much effect, (b) slightly augment or enhance older processes, (c) significantly modify the way we do things, or (d) allow us to transform and redefine tasks altogether and allow us to engage in activities inconceivable earlier (Hilton, 2016; Puentedura, 2006, 2010). The higher up in this taxonomy that technology functions, the more value it brings. The use of technology in the BL group at ABC School provided greater accessibility and equity to all students by promoting the principles of universal design for learning that would be impossible otherwise. It facilitated the differentiation of tasks with varying difficulty depending on their demonstrated competencies of students, presented immediate feedback to each and every student to self-reflect and make decisions about how they would like to proceed in the sequence, and provided the teacher with student engagement and learning data automatically on a daily basis that allowed her to adjust her small group and remedial instruction every week. None of this would have been possible to do in a class of 40 students and one teacher, without the help of technology. In this way, the use of technology in the BL group operated at the highest level of value addition by *transforming and redefining* teaching and learning in the classroom (Hilton, 2016; Puentedura, 2006, 2010).

Our second hypothesis was that students in the treatment group would achieve significantly better learning outcomes than students in the group receiving traditional instruction. This hypothesis was confirmed, and echoes findings from prior studies where students engaged in BL were found to outperform their peers receiving only face-to-face instruction (Means et al., 2009, 2013; Prescott et al., 2018; Seage & Türegün, 2020). As such, the treatment group's posttest performance was significantly higher with an effect size of $d=0.34$, which was larger than the weighted average effect size between posttest scores found in previous meta-studies related to the effectiveness of educational technology integration in K-12 mathematics education (Cheung & Slavin, 2013; Delgado et al., 2015; Li & Ma, 2010). Further, the size of change in performance over time was such that the treatment group (at $d=0.97$) was higher than the annual normative growth in math performance for grades 2–3 at $d=0.89$ (Bloom et al., 2008), while the size of change in performance for the control group (at $d=0.68$) was below the norm (Bloom et al., 2008). Finally, the baseline to end-line trend in student performance showed that the number of students in the lowest and highest percentile ranges changed unfavorably for the control group and favorably for the treatment group. This echoes findings from past studies where the completion of Zearn lessons correlated with a decline in the number of students in the lowest achievement category and an increase in the number of students in the proficient category (Sharma & Hasim, 2019). A similar finding was presented in prior research where a group of students with lower initial reading scores showed much higher performance improvement post-receiving BL instruction, in comparison with the control group, such that the differences between both groups eventually disappeared (Macaruso et al., 2020).

5.1 Limitations

To begin with, the classroom observation tool was developed by the researchers by picking and collating different indicators from within the Framework for Teaching tool (Danielson, 2013), thereby affecting the adapted tool's validity. Another limitation was that the baseline EasyCBM test had one question related to US currency that was contextually irrelevant for the study's students, while the midline and end-line tests had two questions each. Finally, EasyCBM was aligned with the Common Core State (CCS) standards of the USA instead of the Indian ICSE standards that ABC School followed. EasyCBM was chosen because no norm-referenced standardized test validated by peer-reviewed studies was available in the Indian context. But, this created potential for bias towards the treatment group's outcomes because it implied that Zearn was EasyCBM-aligned, while the control group's curricular resources were not necessarily so. However, in order to mitigate any potential bias, an extensive curricular mapping exercise was undertaken and documented at the outset to ensure alignment of learning objectives, topics, and pace of content covered by (a) the treatment and control group, and (b) EasyCBM.

6 Conclusions

A key driver of the problem with teaching and learning of math in the Indian schooling context is that curricular resources and large classroom sizes are incompatible with learner-centered pedagogy. However, the positive findings from ABC School's implementation of BL provide hope for a potential solution. Considering the socio-economic inequities, geographic constraints, limited access to study material, and dearth of competent teachers, BL interventions hold great promise for transforming the schooling landscape of the country (Kundu, 2018). Studies on BL are slowly emerging from India, but the current pool of context-relevant research is still very scarce. It is hoped that this paper inspires longitudinal experimental studies across diverse geographical contexts, school and student demographics, grade levels, and academic disciplines, in India and countries of a similar profile. This will help build an empirical foundation for technologically aided evidence-based interventions that may support school reform efficiently and effectively.

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Declarations

Conflicts of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all participants included in the study.

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