IXL supports academic growth through spaced study sessions when learning challenging material

Students using IXL Math and IXL Language Arts learned challenging material more effectively when they spaced out practice over multiple sessions, relative to practicing challenging material in a single session.

Schonberg and colleagues (2025) examined how two well-established learning science principles—spaced learning and productive struggle—interacted to benefit math and English language arts (ELA) learning on IXL. IXL is a widely-used teaching and learning platform deeply rooted in learning sciences research (for more information, see [IXL's Design Principles]). It covers all four core subjects (i.e., math, language arts, science, and social studies) as well as Spanish.

Spaced learning and productive struggle are two principles that fall under the larger umbrella of what are known as "desirable difficulties" in learning. "Desirable difficulties" describe characteristics of a learning environment that can seem counterintuitive or uncomfortable for the learner in the moment but in the long term substantially improve learning outcomes.

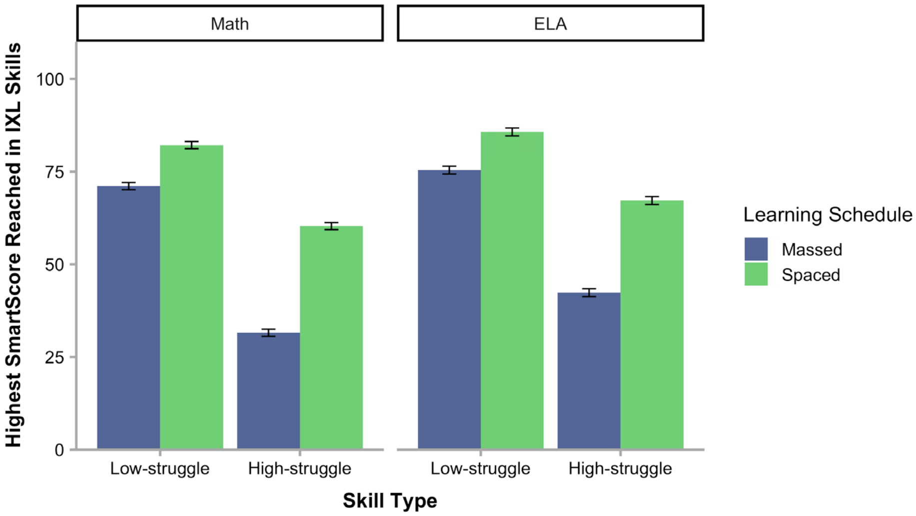
In *spaced learning*, study sessions are spaced apart in time (e.g., multiple sessions over several days), rather than massed together (e.g., one long session). Although learners often prefer to mass their study, research shows that spaced learning is much more effective for long-term retention.

Productive struggle describes the idea that students benefit from engaging with new problems that, to the student, do not have obvious solutions, yet are within the student's reach to solve. Engaging in productive struggle helps students connect more deeply with core concepts, rather than focus only on correct answers or rote memorization.

In this study, the authors aimed to test the hypothesis that spaced learning and productive struggle would interact with each other; specifically, they predicted that spaced learning would provide a larger benefit when students were learning challenging material, compared to easier material.

The participants in this study included 9,216 K-5 students from a large, urban district in the Midwestern U.S. The authors examined students' IXL usage in math and ELA during the 2022-23 school year. When students use IXL, they complete practice problems organized within skills, or specific topic areas within a subject, and IXL uses a proprietary *SmartScore* to measure a student's proficiency within a skill. In this sample, students practiced 8,621 unique IXL Math skills and 2,676 unique IXL ELA skills during the study period.

For each skill that each student practiced, the authors classified the skill as (1) massed or spaced (depending on whether it was practiced over one session or multiple sessions), and (2) low-struggle or high-struggle (depending on how many questions were answered incorrectly, with more incorrect answers indicating a high-struggle skill for that student).



As shown in the figure, there was a significant effect of learning schedule on student growth: Students reached a higher SmartScore when they practiced skills on a spaced schedule compared to a massed schedule. There was also a significant effect of productive struggle, such that students reached a higher SmartScore in low-struggle skills compared to high-struggle skills. Most importantly, there was a significant interaction between learning schedule and productive struggle, such that **spacing had the largest benefit when students were engaged in productive struggle** (i.e., practicing high-struggle skills).

Many students shy away from learning that feels difficult. However, this study shows that implementing "desirable difficulties" like practicing challenging skills across multiple sessions can have significant positive effects on student growth in both math and ELA. We recommend that educators encourage their students to push themselves and space their study—even if growth feels modest at first, the long-term benefits of learning these strategies can be far-reaching. Indeed, students who incorporate spacing may see benefits beyond their test scores: Effective self-regulation of learning can also enhance students' sense of autonomy, which can in turn support their motivation to learn and succeed. By encouraging mastery of difficult material that is just within reach, educators can help students truly maximize their academic growth.

Reference

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ORIGINAL RESEARCH

Spaced Learning Supports Productive Struggle in an Online Learning Platform

Christina Schonberg[1] · **Mary Hargis Becker**[1] · **Xiaozhu An**[1] ·
Bozhidar M. Bashkov[1]

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Abstract

The goal of this study was to investigate how two well-established learning science principles—spaced learning and productive struggle—interact to benefit learning on a widely-used educational technology platform (IXL). When students use IXL, they complete practice problems organized within skills, or specific topic areas within a subject. We obtained IXL skill practice data in math and English language arts from 9,216 K-5 students in one Midwestern school district. We then classified students' practice on each skill as (1) massed or spaced, and (2) low-struggle or high-struggle. We hypothesized that spacing skill practice would have a smaller impact on learning in low-struggle IXL skills (i.e., skills in which students made few errors), whereas spacing would have a larger impact on learning in high-struggle (i.e., challenging) IXL skills. Using multilevel models to analyze student practice of over 11,000 IXL skills, we found that spaced practice was more beneficial than massed practice ($ps < .001$). Key to our hypothesis, we found a significant interaction between learning schedule and productive struggle, such that the spacing effect was largest for high-struggle skills ($ps < .001$). These results provide large-scale evidence in a real-world educational setting that productive struggle supports student learning and that spaced learning can further enhance the positive effects of productive struggle. Practically speaking, these findings suggest that educators can benefit from using e-learning tools that incorporate spaced learning as one strategy to support students' productive struggle, which in turn can boost academic growth.

Keywords Spacing effect · Productive struggle · Edtech · Online learning

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✉ Christina Schonberg
cschonberg@ixl.com

[1] IXL Learning, Inc., San Mateo, USA

1 Introduction

Decades of learning science research have established best practices that aim to support efficient and enduring learning. However, much of this research has been conducted in the lab (e.g., Gay, 1973; Roher & Taylor, 2007) or in in-person settings in which the pace and content of instruction are determined by the teacher (see Rohrer, 2015). With the adoption of educational technology (edtech) platforms skyrocketing in recent years (Instructure, 2024), students now have more flexibility in choosing when and what to learn. Thus, it is important to understand how learning principles that have been established in more traditional settings transfer to flexible online environments, especially as applying some promising learning strategies in naturalistic settings presents unique challenges beyond those observed in the lab (Hulleman & Cordray, 2009). In the current study, we examine how two such principles may improve student learning in an e-learning context.

While lab-based research has uncovered helpful strategies to increase long-term retention and learning, many of these strategies are not spontaneously applied by a learner self-regulating their own study, partly because many people think that studying should feel easy and fluent. "Desirable difficulties" describe characteristics of a learning environment—including varying the conditions of study, providing minimal guidance during problem solving, using tests as study events, and more—that, while potentially uncomfortable for the learner in the moment, substantially improve long-term retention (Bjork, 1994; Bjork & Bjork, 2011). There are certainly difficulties that are "undesirable" for learning (e.g., studying while distracted, Gaspelin et al., 2013). However, the right degree of challenge can be helpful (i.e., "desirable"). The goal of this study was to investigate how two well-established but counterintuitive principles—spaced learning and productive struggle—interact to benefit learning on an edtech platform.

1.1 Theoretical Background

Learning can be influenced by both the distribution of the material to be learned (i.e., *when* and *in what order* study occurs) as well as its content (i.e., *what* is studied). Conventional classroom lessons are often structured in a "massed" format (Lyle et al., 2020). For example, students may practice several problems in a row that require the same formula to solve each problem (see Rohrer et al., 2020) and then move on, not encountering this material again until an end-of-unit test. While massed learning is commonly used and often endorsed by students and educators alike (Pyc & Dunlosky, 2010), this instructional format can be detrimental in the long term, as memory for massed information is prone to errors. In fact, an extensive body of empirical work has shown that retention improves when study sessions are spaced apart in time, a benefit known as the *spacing effect* (e.g., Carpenter et al., 2022; Cepeda et al., 2006; Dunlosky et al., 2013; Ebbinghaus, 1885/1964; Mawson & Kang, 2025; Rohrer, 2015).

The spacing effect replicates across domains from motor skills to mathematics (Barzagar Nazari & Ebersbach, 2019; Carpenter et al., 2009; Knabe et al., 2023), and there is evidence that its benefit also extends to digital contexts (at least among adult learners, Carvalho et al., 2020). One potential explanation for this effect is that spacing out study sessions allows the student to refresh working memory resources that were depleted by acquiring new knowledge and potentially correcting misconceptions (see Chen et al., 2021). Even in light of its benefits, the implementation of the spacing effect into classrooms has been challenging (Son & Simon, 2012), partly because much of the lab-based work on spacing has used stimuli, learning schedules, and/or retention intervals that do not reflect real-world educational contexts (e.g., Ebbinghaus, 1885/1964; see Dempster, 1989). In addition, spacing does not allow educators to "teach a unit and dust off their hands quickly" (Vash, 1989, p. 1547); that is, effectively spacing study requires substantial time and effort by both teachers and learners. Students can also be reluctant to engage in spacing: When given the choice, most first-grade students preferred to mass their study (Son, 2005; see also Hartwig et al., 2022). Questions remain regarding the benefits of spacing in online platforms, especially those that would provide the most benefit for students when they appropriately self-regulate their learning.

In addition to choosing *when* to learn, which introduces the opportunity for spaced learning, students using edtech tools often have a choice in *what* to learn, which affords the opportunity for productive struggle. First introduced in the context of mathematics learning by Hiebert and Grouws (2007), *productive struggle* is the idea that students benefit from engaging with new problems that do not have obvious solutions, yet are within the student's reach to solve. In general, productive struggle involves a combination of creativity, perseverance, and critical thinking; it is theorized to be beneficial because it emphasizes the importance of putting ideas together and the feeling of discovery, which can spark excitement and support motivation for continued learning (see Leinwand et al., 2014); for review, see Young et al., 2023). Under this framework, deeply engaging with challenging material is much more important for learning than answering questions correctly.

Parallel to the broader notion discussed above that not all difficulties are desirable, it is important to note that not all struggle is productive. For example, wrestling with overly challenging material to the point of frustration does not benefit students. Rather, productive struggle occurs when students solve new problems at the edge of their zone of proximal development (Vygotsky & Cole, 1978): problems that are within reach, but may require them to deepen their conceptual understanding or connect ideas in a new way. Engaging in productive struggle helps students connect more deeply with core concepts, rather than focus only on correct answers or rote memorization (e.g., Warshauer, 2015). Students are likely to reap the largest academic gains when problems are appropriately difficult given their current knowledge, compared to working on problems that are too easy (that is, practicing "unproductive success") or too hard (that is, experiencing "unproductive failure"; Kapur, 2016).

To date, much of the research on productive struggle has focused on preservice and inservice teachers' attitudes towards struggle, as well as best practices for encouraging productive struggle in students (for a review, see Young et al., 2023). These studies have found that adults generally report favorable views of this type of challenge (e.g., Russo et al., 2020). However, similarly to the difficulties of implementing spaced study, it can be difficult to structure learning environments in a way that encourages productive struggle (e.g., Baker et al., 2020; Russo et al., 2020; Sayster & Mhakure, 2020; Vazquez et al., 2020). This difficulty exists partly because students in a classroom may have different levels of background knowledge or support needs, such that a concept that is appropriately challenging for one student may be too easy for another.

Much of the theory and research on productive struggle has examined the roles of elements found in traditional classroom settings (e.g., lesson structure, teacher factors). In contrast, far fewer studies have measured the impact of productive struggle on students' learning and growth. These studies, though limited in number, do suggest a positive relationship: Engaging in productive struggle has been linked to developing a deeper understanding of math (O'Dell, 2018), enhancing creative problem-solving (Roble, 2017), increasing persistence (Leitze & Soots, 2015), and achieving academic success (Roble, 2017). In addition, two recent studies found that productive struggle boosts achievement in both math and English language arts (ELA) in an online learning setting (Schonberg et al., 2024; Schonberg, 2023a). However, a gap in the literature persists: The ways in which students can benefit from productive struggle across diverse contexts, especially as it interacts with other beneficial features of real-world learning environments, remain understudied.

1.2 Aims and Hypotheses

As edtech platforms grow in popularity, it is increasingly important to ensure that educators and students are optimizing their use of such tools, but students do not tend to engage spontaneously in practices that are the most beneficial for their learning. For example, they often prefer massed learning over spaced learning (Hartwig et al., 2022; Son, 2005); they also often choose not to engage in productive struggle, and instead work through problems that they find easier (Schonberg et al., 2024; Schonberg, 2023a). Currently, the guidance provided by many online learning platforms regarding optimal usage strategies is fairly general. For example, a platform may recommend that students spend a certain amount of time on the platform every week (e.g., 45 minutes). Under this limited guidance, students may simply use the platform in one long session each week, even though it could be more effective to engage in several shorter sessions. This study addresses the potential discrepancy between what students *should* do with their autonomy on online platforms and what they *actually* do, with the broader goal of helping students and educators maximize the benefits of e-learning tools.

The primary aim of the present study was to investigate how learning schedule (i.e., spaced vs. massed practice) and productive struggle could impact student learning on one popular edtech platform, IXL. When students use IXL, they complete practice problems organized within *skills*, or specific topic areas within a subject. We hypothesized that learning schedule would have a relatively small impact within IXL skills in which students answered the majority of questions correctly and did not show evidence of struggling; if a student is not struggling with a skill, they likely will progress steadily through the skill regardless of whether they engage in massed or spaced practice. In contrast, we predicted that learning schedule would have a larger impact within skills in which students showed evidence of struggling (i.e., answering many questions incorrectly); if a student's cognitive resources have been depleted by effortful learning, they may benefit from taking a break from that skill (see Chen et al., 2021) and returning later.

2 Method

2.1 Participants

We partnered with a large, urban district in the Midwestern U.S. for this project, and our sample consisted of 9,216 students (51.7% male) in grades K-5.[1] Overall, 15.0% of students were enrolled in special education programs, and 8.9% of students were classified as gifted. The racial/ethnic makeup of the sample was as follows: 73.6% White, 10.3% Hispanic, 6.2% Asian, 6.1% multiracial, and < 5% any other race.

2.2 Edtech Platform: IXL

We chose to study the interaction of spacing and productive struggle in an online learning platform that was a) popular among educators and students, so that our findings would generalize to a larger population of learners, and b) supported by empirical research in both design and efficacy. The edtech platform we investigated in this study was IXL—a widely-used teaching and learning platform covering all four core subjects (i.e., mathematics, language arts, science, and social studies) and Spanish. IXL is deeply rooted in learning sciences research (see Bashkov et al., 2021) and draws from research on learning progressions (Briggs et al., 2015; Corcoran et al., 2009), Bloom's Taxonomy (Anderson et al., 2001; Bloom & Krathwohl, 1956), and Webb's (1997) Depth of Knowledge theory, carefully breaking concepts down so that students can gradually work towards mastering complex ideas. For example, when a student practices on IXL, they begin by answering questions intended to test their memory and understanding. Once understanding is established, students move on to apply their knowledge in novel contexts and, eventually, to create their own new solutions to problems (Bloom & Krathwohl, 1956). In addition, IXL skills (i.e., topic areas within a subject) follow a scaffolded progression—for example, a sequence of addition skills starts relatively simply (focusing on adding one-digit numbers that sum to 10, then adding one-digit numbers that sum to 20) before becoming more complex (adding three one-digit numbers, adding three one-digit numbers in word problems, adding four or more one-digit numbers, etc.). Furthermore, content *within* each skill follows a scaffolded progression as well, such that questions become more difficult as students make progress within a skill (e.g., practicing $2+1+3+2$ before moving on to $7+3+9+4$).

Other key research-supported components of IXL include its adaptive algorithm that tailors question difficulty to students' knowledge—supporting productive struggle and differentiated instruction (Deville, 1993, as cited by Linacre, 2000)—as well as the immediate detailed feedback given to students when they answer questions on the platform incorrectly (Kornell et al., 2009; Perie et al., 2009), which supports students' self-reflection and analysis of their current understanding of the content. Finally, IXL is designed to support student autonomy and choice. A core component of Self-Determination Theory (Deci & Ryan, 1985, 2000; Ryan & Deci, 2017), autonomy plays a key role in student motivation, learning, and success (Tullis et al., 2018). When students play an active role in making decisions

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[1] As is common in large districts, there was variation across schools in how IXL was implemented. However, the schools within this district were highly similar in terms of student demographics, and the goal of the study was to examine the effects of interest across a variety of implementations. Student data are therefore analyzed together as a district (with students nested within schools).

about their learning process (e.g., when they self-regulate their learning), they develop a sense of ownership in their learning; this sense of ownership, in turn, can itself further boost learning (Grabinger & Dunlap, 1995). In recognition of these design components and others not discussed here (see Bashkov et al., 2021, for a more in-depth discussion of the design principles underlying the platform), IXL has earned the research-based design certification from the education nonprofit organization Digital Promise (Digital Promise, n.d).

IXL's efficacy has been studied extensively. For example, an independent randomized controlled trial found a significant positive impact of IXL on students' math achievement in grades 3–5 (Copeland et al., 2023). Other independent or third-party-vetted quasi-experimental studies have found similar effects (e.g., Altermatt et al., 2022; Mislevy et al., 2021). IXL's internal research, spanning more than 200 studies, shows that students who use IXL reach higher levels of academic achievement than students who do not (e.g., An, 2021; An et al., 2024; Hargis Becker et al., 2025; Liu et al., 2025). Furthermore, among students who use IXL, those who use the platform more (e.g., answer more questions) experience larger academic gains (e.g., An et al., 2023; Hargis, 2023; Schonberg & Hochstein, 2022). These effects have been replicated across subjects, grade levels, geographic regions (e.g., Hargis, 2024; Hargis Becker, 2025a, 2025b; Schonberg, 2023b, 2024a, 2024b), and student subgroups, such as English learners, students receiving special education services, and high-achieving students (An, 2022, 2025; Schonberg & Hargis, 2023, 2024).

When students practice skills on IXL, their progress is recorded through the *SmartScore*, a proprietary algorithm that evaluates student knowledge based on question difficulty and response patterns. Within each skill, a student's SmartScore for that skill increases after a correct response and decreases after an incorrect response. Although the SmartScore ranges from 0 to 100, it is not a percent correct score: A SmartScore of 100 is always attainable. As students make progress within a skill, the SmartScore gains for correct answers get smaller, challenging students to show that they truly understand the material and supporting their development of a mastery orientation (Elliott & Dweck, 1988). Furthermore, the forgiving design of the SmartScore algorithm helps to instill a growth mindset (Dweck, 2006) in students, supporting the belief that they can master challenging material with sufficient effort (e.g., it is always possible to reach a SmartScore of 100). Reaching higher SmartScores in IXL skills is positively related to students' academic achievement (e.g., An et al., 2022), demonstrating that the SmartScore itself can be a valuable tool for measuring how well a student truly understands key academic concepts. Therefore, in this study, the SmartScore served as the measure of students' learning.

2.3 Data Source and Definitions

2.3.1 IXL Usage Data

We obtained students' IXL usage data during the 2022–23 school year from IXL. The duration of the study period was 41 weeks. For each student in the sample, we obtained the following data for each question they answered on IXL: the skill's unique identifier (allowing us to distinguish between skills), the timestamp after each response, and the SmartScore after each response. As described above, the SmartScore increases after a correct response and decreases after an incorrect response. We used this information to classify responses as correct or incorrect. Because students can restart a skill and keep practicing after they have reached the maximum SmartScore (100), we included only data up to the first time a student reached a SmartScore of up to 100 in a given skill. Finally, we only analyzed skills in which the majority of the learning trajectory was captured during the study period. To this end, we included only skills in which a student had reached a SmartScore of less than 20 at the beginning of the school year, indicating that they had engaged in very little (if any) practice within that skill prior to the beginning of the study period.

2.3.2 Productive Struggle

It is important to note that we did not categorize students overall as struggling or not; rather, we classified each *skill* practiced by each student as either high-struggle or low-struggle based on the SmartScore pattern within the skill during practice. We used a threshold of 80% accuracy to classify skill practice as low-struggle (≥80% correct) or high-struggle (<80% correct). This threshold of 80% was selected because if a student is answering the vast majority of questions correctly, they likely already have a solid grasp of the material covered in that skill and are therefore unlikely to be struggling; it is also consistent with the threshold used in prior research on students' productive struggle on an edtech platform (Schonberg et al., 2024).

2.3.3 Spaced Learning

Practice on a given skill was classified as spaced if the student answered questions within the skill over at least two distinct sessions. A session break was defined as at least a 20-min interval between question answers. [2]During this interval, students may have practiced other skills, or they may have taken a break from deliberate learning entirely; for the purposes of this study, we classified both types of behavior as "spacing" (e.g., Carpenter et al., 2012). Skills that were practiced with no session breaks were classified as massed.

2.4 Analytic Approach

We specified and tested separate multilevel models for each subject (math and ELA). Each model included random intercepts by student, by school, and by skill (to account for the fact that some skills may be inherently more difficult than others). The outcome variable was the highest SmartScore reached within each skill. To control for the amount of experience each student had practicing each skill, we also included number of questions answered in the skill as a covariate. The key predictors in the models were learning schedule (spaced vs. massed), productive struggle (low-struggle vs. high-struggle), and a learning schedule × productive struggle interaction term.

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[2] There is no single duration of a gap between learning sessions that is optimal in all learning environments (Cepeda et al., 2008; Rogers, Nakata, & Chiu, 2025; Walsh et al., 2023); typical gaps found in previous studies range from a few seconds to days or weeks (Ebersbach et al., 2022; Mawson & Kang, 2025). In the current study, we also investigated 5 min, 10 min, and 60 min as potential intervals for defining session breaks. The pattern of results for each threshold was extremely similar to the results we found for the 20-min interval. We chose the 20-min interval because this interval allows for instances where students may have actively worked on one problem for several minutes before submitting their response.

Table 1 Descriptive statistics of students' weekly IXL skills practiced during the 2022–23 school year

Productive struggle	Learning schedule	IXL Math				IXL ELA			
		M	*SD*	Min	Max	*M*	*SD*	Min	Max
Low-struggle	Massed	1.03	1.11	0.03	21.82	0.79	0.82	0.03	13.85
Low-struggle	Spaced	0.33	0.40	0.03	18.21	0.27	0.29	0.03	3.51
High-struggle	Massed	0.42	0.39	0.03	3.72	0.32	0.33	0.03	3.33
High-struggle	Spaced	0.25	0.27	0.03	2.79	0.23	0.28	0.03	3.26

M mean, *SD* standard deviation

Table 2 Regression model predicting highest SmartScore in an IXL math skill from productive struggle and learning schedule

Predictor	*b*	*SE*	95% CI	β	*t*	*p*
(Intercept)	71.07	0.47	70.15 to 71.99	−0.09	150.57	<.001
Number of questions answered[1]	0.29	0.00	0.29 to 0.29	0.24	290.49	<.001
High-struggle skill[2]	−39.52	0.08	−39.68 to −39.36	−1.15	−481.93	<.001
Spaced skill[3]	11.09	0.08	10.93 to 11.25	0.32	138.26	<.001
Struggle * Spacing interaction	17.67	0.13	17.41 to 17.92	0.51	137.18	<.001

Dependent variable: highest SmartScore reached in an IXL Math skill. *b* unstandardized regression coefficient, *SE* standard error, *CI* confidence interval, *β* standardized regression coefficient

[1] Grand-mean centered

[2] Dummy coded; low-struggle skills as reference group

[3] Dummy coded; massed skills as reference group

3 Results

Students practiced 8,621 unique IXL Math skills and 2,676 unique IXL ELA skills during the study period; on average, students practiced 1.96 skills per week in math (*SD* = 1.86) and 1.50 skills per week in ELA (*SD* = 1.43). In both math and ELA, the majority of skills that students practiced were classified as low-struggle and massed (average weekly low-struggle, massed math skills: *M* = 1.03, *SD* = 1.11; average weekly low-struggle, massed ELA skills: *M* = 0.79, *SD* = 0.82). High-struggle, spaced skills comprised the smallest category of skills that students practiced (average weekly math *M* = 0.25, *SD* = 0.27; average weekly ELA *M* = 0.23, *SD* = 0.28). Additional descriptive statistics of students' platform usage are presented in Table 1. On average, when students practiced skills on a spaced schedule, they did so across approximately three sessions per skill (*M* = 2.8, *SD* = 1.5).

In both math and ELA, we found significant effects of learning schedule and productive struggle. A summary of the results from each regression model can be found in Table 2 (math) and Table 3 (ELA). The unstandardized *b* coefficients indicate the expected difference in highest SmartScore reached depending on each skill's characteristics (massed vs. spaced learning schedule; low-struggle vs. high-struggle). Key to our hypothesis, we found a significant interaction between learning schedule and productive struggle (math *b* = 17.67, 95% CI [17.41, 17.92]; ELA *b* = 14.58, 95% CI [14.31, 14.85]; *p*s < .001). Specifically, as hypothesized, spaced practice had a larger positive impact on students' progress in high-struggle skills, relative to its impact on low-struggle skills; this pattern is visualized in Fig. 1, wherein the size of the gap between the bars indicating "massed" and "spaced" practice is larger for skills classified as high-struggle (right side of each panel) vs. low-struggle (left

Table 3 Regression model predicting highest SmartScore in an IXL ELA skill from productive struggle and learning schedule

Predictor	*b*	*SE*	95% CI	β	*t*	*p*
(Intercept)	75.42	0.53	74.38 to 76.46	−0.07	143.21	<.001
Number of questions answered[1]	0.24	0.00	0.24 to 0.24	0.27	259.00	<.001
High-struggle skill[2]	−33.08	0.09	−33.26 to −32.90	−1.04	−350.02	<.001
Spaced skill[3]	10.28	0.09	10.10 to 10.46	0.32	113.18	<.001
Struggle *Spacing interaction	14.58	0.14	14.31 to 14.85	0.46	102.49	<.001

Dependent variable: highest SmartScore reached in an IXL ELA skill. *b* unstandardized regression coefficient, *SE* standard error, *CI* confidence interval, *β* standardized regression coefficient

[1] Grand-mean centered

[2] Dummy coded; low-struggle skills as reference group

[3] Dummy coded; massed skills as reference group

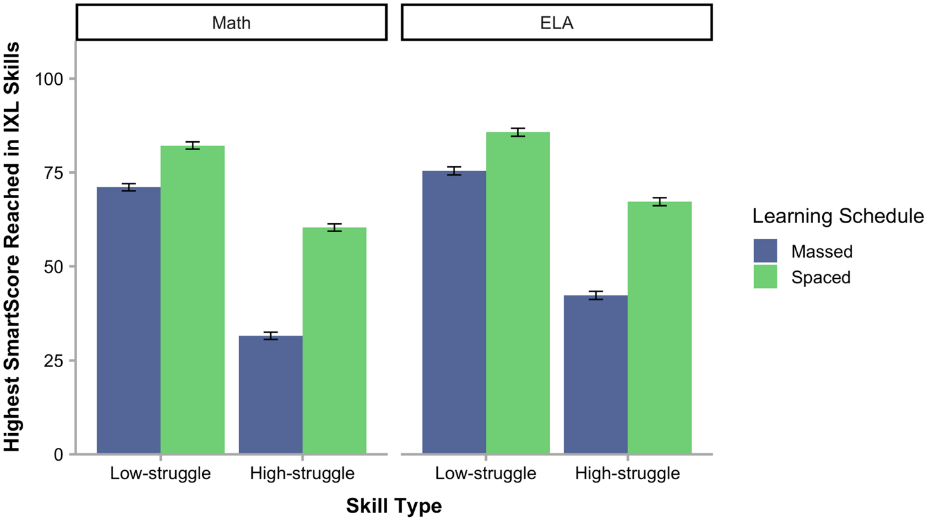

Fig. 1 Model-estimated marginal means of highest SmartScore reached by condition and subject. *Note.* Error bars indicate the 95% confidence interval of the estimate.

side of each panel). We also found a main effect of learning schedule: Relative to a massed schedule, practicing on a spaced schedule was associated with approximately a 10-point increase in highest SmartScore (math $b = 11.09$, 95% CI [10.93, 11.25]; ELA $b = 10.28$, 95% CI [10.10, 10.46]; $ps < .001$). Finally, there was a main effect of productive struggle, such that the maximum SmartScore reached in high-struggle skills was about 30–40 points lower than the maximum SmartScore reached in low-struggle skills (math $b = -39.51$, 95% CI [−39.68, −39.36]; ELA $b = -33.08$, 95% CI [−33.26, −32.90]; $ps < .001$).

As shown in Fig. 1, students benefited the most from spacing when they were engaging in productive struggle (i.e., when the skill was difficult for them, as evidenced by answering at least 20% of questions incorrectly when practicing that skill). These results provide empirical support for a strategy that educators and students may already consider: taking a break from difficult material and returning to it later. Previous research has shown that high-struggle practice on IXL has a much larger impact on academic achievement than low-struggle practice (Schonberg et al., 2024; Schonberg, 2023a); based on these past findings, as well as those of the present study, we posit that spacing out practice sessions of high-struggle skills would especially benefit students' learning and achievement.

4 Discussion

The goal of this study was to address a gap in the literature by investigating how spacing and productive struggle interact to impact student learning on an edtech platform, IXL. By using IXL's SmartScore as a measure of student knowledge, we found that students learned more if they practiced a skill over multiple sessions, each separated by at least 20 min (i.e., spaced practice). We also found that students tended to reach a higher SmartScore in low-struggle skills, relative to high-struggle skills (consistent with the findings of Schonberg et al., 2024). Most importantly, we found an interaction between learning schedule and productive struggle, such that spacing had the largest benefits when students were engaged in productive struggle.

As e-learning tools continue to gain popularity, how can educators promote the application of effective learning strategies? A thoughtful approach is required, not just in educators' structuring of course content, but also in assisting students to incorporate such techniques into their own, self-regulated learning. Previous findings suggest that, when left to their own devices, learners do not often implement desirable difficulties (e.g., Hartwig et al., 2022; McCabe, 2011). For example, students often choose to block their study time, such as when "cramming" for a test (Susser & McCabe, 2013). Indeed, we found that students in this sample tended to engage in massed, low-struggle practice above other types of practice (Table 1). Although this type of practice may feel helpful to students in the moment, the current results suggest that their time is likely better spent engaging in multiple practice sessions of high-struggle skills. Because spaced, high-struggle practice was the most effective (yet least frequent) type of practice in the sample we studied, we strongly recommend that educators highlight the importance of spaced learning to their students, as well as the importance of pushing themselves to learn material at an appropriately-challenging level (see Yan et al., 2024, for a detailed discussion of how educators and students can practically integrate these best practices). Students who incorporate spacing may see benefits beyond memory for the to-be-learned material: Effective self-regulation of learning schedules can also enhance a students' sense of autonomy, which can in turn support their motivation to learn and succeed (see Zimmerman & Schunk, 2004). Educators and learners alike should be aware that although spacing study sessions may *initially* lead to lower performance after returning from a break due to some amount of forgetting, learners in this study and others have been shown to benefit in the longer term (see Bjork & Bjork, 2020).

5 Limitations

It is worth noting that in this study, we focused on *spacing,* or returning to a topic in several sessions across time, rather than the related concept of *interleaving*, or mixing the study of different types of material. We do not know precisely what students in this sample were doing between their study sessions of a particular IXL skill, only that they were not continuously practicing the same skill. Some prior studies have attempted to disentangle the benefits of spacing and interleaving, thereby demonstrating their individual contributions to learning (e.g., Taylor & Rohrer, 2010), while other work has found evidence that the benefits of interleaving are the *product* of spacing (Foster et al., 2019). More recent research on the mechanisms behind spacing and interleaving suggests that maximizing the benefits of spacing requires the restoration of depleted working memory resources via rest from intentional practice (in contrast with interleaving, which calls for consistent learning of different concepts; Chen et al., 2021). While spacing and interleaving have been shown in a recent meta-analysis to have substantial effects on learning ($d = 0.85$ and $d = 0.47$, respectively; Donoghue & Hattie, 2021), future work should explicitly address how the potentially distinct benefits of spacing and interleaving manifest in an educational technology context.

A second limitation of this work is that, due to the scale of the study and the nature of how data were collected, we did not have access to information about key contextual variables that likely also influenced individual students' practice patterns. For example, teachers in this district likely varied in the amount of support and direction they provided to students in using the platform; some teachers may have used IXL for differentiated instruction, increasing the likelihood that each student was practicing appropriately challenging skills, whereas other teachers may have used IXL as a supplement to their standard curriculum, assigning the same, curriculum-aligned skills to every student. There was also almost certainly variability in student-level characteristics, such as home environment, motivation, and academic self-efficacy, which could have impacted students' degree of engagement and persistence (e.g., Schunk & DiBenedetto, 2022) as well as their frequency of practicing skills on IXL. By including these variables, future work could uncover a more nuanced understanding of how these real-world factors influence students' learning in online environments.

Additionally, due to methodological constraints, this study did not include information about students' overall math knowledge at baseline. Therefore, students could have had knowledge that was not accounted for until they began practicing a given skill on IXL. For example, a student could have known how to multiply numbers by 2 before practicing that skill on IXL, but their initial SmartScore of 0 would be treated the same as that of a student who had never encountered the concept before (i.e., this type of skill would have been included in the current analysis since it met the criteria for an "unknown" skill). The SmartScore algorithm does, however, quickly account for students' current knowledge levels—often within a few questions. Though "struggle" was operationalized at the *skill* level in this study, there were some *students* who struggled more broadly, performing below their grade level within a subject. It is possible that these lower-achieving students could reach a plateau in their progress over time; that is, having reached the edges of their current knowledge they could experience a levelling-off of growth (see Schonberg et al., 2025, for an investigation of this phenomenon). In future work, incorporating baseline math ability could allow for a finer-grained analysis of the potentially-differential effects of spacing and productive struggle on higher-achieving and lower-achieving students' math learning.

6 Future Directions

This study provides evidence that spacing and productive struggle interact to impact student learning. One avenue for future research is to investigate the mechanism underlying this interaction: that is, what occurs during spacing that helps make students' struggles productive? The forgetting that happens between learning instances can be key for abstracting and generalizing new concepts (e.g., Vlach et al., 2022); abstraction and generalization could indeed play a key role in students' mastery of new, challenging concepts. It may also be that when students take breaks from difficult concepts, they continue to unconsciously process the material, as has been suggested by studies of insight and problem-solving (e.g., Caravona & Macchi, 2023; Gilhooly, 2016). Thus, we suggest that future work examine the interaction between spacing and productive struggle under these theoretical frameworks. In addition, practical work can examine how learners seek out or avoid these desirable difficulties in the real world, such as when using an online learning platform. As autonomous e-learning programs like massive open online courses (MOOCs) continue to grow in popularity, it would likely benefit students, educators, and researchers to further examine how appropriate self-regulation (or lack thereof) can impact learning outcomes in these contexts (see Carvalho et al., 2020).

IXL provides support to help students fill in knowledge gaps while also empowering them to decide what questions to answer and when. However, learners do not always choose optimal study strategies, as evidenced by the popularity of massing in this study (and in many others, see Hartwig et al., 2022; Yan et al., 2024). Students will likely continue to gain freedom in deciding when and what to learn, and their ability to effectively regulate their own learning (e.g., by choosing appropriate learning strategies) will become increasingly important. Although it is not currently clear how best to promote students' use of desirable difficulties in the classroom, some promising interventions have recently been established in a lab context (Onan et al., 2024); however, more work is needed to determine their effectiveness in a naturalistic education setting.

As the classroom is often more a complex learning environment than a lab, this area of inquiry would benefit from a methodologically diverse approach, including subgroup analyses, examination of platform logs, and experimental manipulation of an intervention based on desirable difficulties. Additionally, qualitative techniques such as student and teacher interviews could provide a richer understanding of students' study decisions, including whether students who spaced their learning did so deliberately or because they were unintentionally distracted (it stands to reason that deliberate spacing would represent more sophisticated metacognition, and may be associated with higher achievement in that domain). Taken together, these quantitative and qualitative methods could clarify the optimal implementation of spacing and productive struggle, including how the benefits of each may depend on students' prior knowledge levels (e.g., lower-performing students may benefit from milder levels of productive struggle as they gain confidence). Finally, incorporating an extended interval between instances of engagement with a skill or a task could better reflect the real-world classroom emphasis on end-of-year testing; examining memory consolidation over time could further clarify the benefits and potential boundary conditions of spacing and productive struggle (see Smith & Scarf, 2017).

7 Conclusion

In sum, our results highlight the importance of persistence in the context of productive struggle and show that practicing over multiple sessions helps students make progress in learning difficult material. That is, spaced learning is an effective strategy for supporting students' productive struggle in an online setting. By encouraging mastery of difficult material that is just within reach, educators can help students truly maximize their academic growth.

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Declarations

Conflict of interest All authors are full time employees of IXL Learning, the organization that developed the software platform (IXL) that is the focus of this study.

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