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DEVELOPMENT ARTICLE

Supporting children's engagement through learning experience design, situational interest, and user experience: implementing a blended learning math experience in the classroom

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Abstract
With the prevalence of digital technologies in the classrooms, educators continue to seek ways to augment traditional in-person teaching with the benefits of educational technologies, utilizing blended learning approaches. This study investigates the role of learning experience design (LXD) in supporting children's engagement in blended, video-based math lessons on proportional reasoning. The research focuses on operationalizing LXD through the integration of instructional design (ID) techniques to promote situational interest (SI) and prioritize user experience (UX). By combining SI and UX principles, the aim is to foster student engagement in a blended classroom learning environment. The quantitative findings demonstrate significant correlations between students' situational interests, user experience, and their level of course engagement. The results from the multiple regressions also showed that students' situational interests and user experience significantly predicted their course engagement. The qualitative analysis highlights three key themes: the positive impact of Learning Experience Design on student engagement, the pedagogical value of employing multiple solution strategies by the teacher, and the influence of the blended course's user experience on students' learning journey. These mixed-method results provide practical insights for refining future designs, ensuring sustained active engagement and effective math learning within blended learning environments, and preparing for various instructional modalities, including traditional, online, and blended formats.

Keywords Learning experience design · Instructional design · User experience design · Blended learning · Elementary instruction · Mathematics

Introduction

Elementary education may have significant potential to identify practical ways to improve in-person, technology-blended learning experiences through the novel combination of learning experience design (LXD) pedagogies, applied with digital learning technologies, and tested through design-based research (DBR) methods. This unique opportunity

Extended author information available on the last page of the article

arose from the sudden shift to online learning during the COVID-19 pandemic and the subsequent transition back to in-person teaching after the pandemic had subsided. As a result, the extended remote learning context fostered an abundance of "edtech tools" for sustainable deployment that aimed to support a more student-centered learning experience through video and interactivity (Wong & Hughes, 2022; Wong et al., 2022, 2023). Currently, instructors and researchers are exploring modalities in which these "edtech tools," which were previously deployed in remote online settings, might be sustainably integrated into classroom learning contexts. Specifically, there is a growing interest in exploring the benefits of adapting these "edtech tools" to implement blended learning experiences in the classroom.

While elementary schools have faced considerable challenges adapting to the "new normal" in post-pandemic teaching and learning (Macasinag & Camacho, 2023; Reimer & Hill, 2024; Wong et al., 2023), there is still a limited understanding of how educators are implementing, reusing, or repurposing educational technologies introduced during the pandemic in today's classrooms. Past studies highlight concerns around reintegrating students into social settings and adjusting to in-person classroom dynamics (Hashim et al., 2024; Hen et al., 2022; Ladson-Billings, 2021). However, less is known about how these technologies are currently being used and how they might be aligned with evidence-based pedagogical frameworks to enhance learning in today's classrooms. Given the abundance of technological resources and spending made available during the pandemic, from digital collaboration tools to adaptive learning platforms (DOE, 2021; Herold, 2022), there is an opportunity to examine how these tools can be used to create meaningful and engaging learning experiences. Teachers may be using these technologies in new ways, such as blended-learning instruction, facilitating interactive learning, or supporting students' individual learning needs. However, research is still needed to understand the ongoing affordances of these applications and how well they integrate with in-person learning. Exploring these questions can shed light on the potential for educational technologies to enrich elementary education with innovative, research-backed practices.

This study employs a design-based research (DBR) methodological framework, building off of prior iterations of implementations, to evaluate a course design in an elementary mathematics proportional reasoning unit using a blended learning model. By integrating interactive, video-based instruction grounded in the learning experience design (LXD) paradigm, we adapt a curriculum originally created for asynchronous online learning (Mesghina et al., 2024; Wong et al., 2024Zhao et al., 2024) for blended in-person classroom use. The objective is to assess the effectiveness of repurposing an online curriculum for in-person instruction, equipping educators with technology-based learning tools that enhance the classroom environment. This research examines the affordances, limitations, and insights gained from implementing LXD, contributing to the goal of sustainable, technology-enhanced instruction.

A primary concern of this study is to explore how to effectively engage and sustain elementary students' participation and active learning throughout their face-to-face experiences. To address this, we designed and deployed a blended elementary mathematics course focused on proportional reasoning to fifth and sixth grade classrooms. In this context, we define engagement as the attention, curiosity, and interest students exhibit during a blended, in-person video-based math instructional unit. We explore how our design intentions as researchers and practitioners can support student engagement by applying LXD principles, while also examining students' situational interest (SI) as a motivator for sustaining engagement. Few studies have investigated the interrelations between LXD implementation, students' situational interests, user experience (UX), and overall engagement in

blended learning environments. Through this study, we leverage high-quality instructional design to support students' SI, prioritize strong UX to alleviate technical challenges, and investigate how the combination of SI and UX can enhance student engagement, ultimately enriching the educational experience in today's classrooms with innovative, evidence-based practices.

Relevant literature

Given the current study's integration of edtech tools in-person, various factors were identified as having the potential to influence students' levels of engagement in the classroom context. Factors such as situational interest and the combination of the learning experience design and user experience that the learning platform evokes may impact whether students remain engaged with the lesson itself. Reviewing these key bodies of literature informs the theoretical basis of our research to characterize the student learning experience by examining the effects of elementary students' situational interest and user experience on their engagement in a blended video-based learning experience administered in the classroom.

Learning experience design

Learning experience design (LXD) has gained significant attention in educational research and practice due to its focus on creating effective and engaging learning experiences that extend beyond traditional instructional methods. LXD refers to creating learning situations that extend beyond the formal classroom learning environment and often integrate online and virtual technological formats (Ahn, 2019). This design framework involves the intentional and systematic instructional design of learning experiences that are learner-centered, goal-oriented, and incorporate principles from various disciplines (Ahn, 2019; Floor, 2018; Weigel, 2015). Encompassing the development of effective learning experiences catered towards students' needs, LXD enables learners to achieve specific learning outcomes in a human-centered and goal-oriented manner. Importantly, LXD is a departure from the traditional term "instructional design," which is primarily focused on curriculum development and programming instruction to support knowledge acquisition (Correia, 2018). Moreover, Weigel (2015) further defines LXD as an interdisciplinary synthesis of instructional design, teaching pedagogy, cognitive science, learning sciences, social sciences, and user experience design.

In practice, Floor (2018) defines the five fundamentals of LXD as human-centered, goal-oriented, grounded in theories of learning, learning through practice, and being heavily interdisciplinary. First, LXD focuses on understanding learners' needs, motivations, and preferences to create meaningful and engaging learning experiences (Floor, 2018; Wong et al., 2022). Next, the emphasis on goal-oriented design ensures that learning experiences are intentionally designed with clear learning outcomes and objectives in mind (Ahn, 2019; Floor, 2018). Additionally, LXD as a course design framework employs one or more pedagogical frameworks that serve as the basis for the learning theories operationalized in the course (Floor, 2018). Another key component of LXD is experiential learning, where the learning environment promotes active engagement through hands-on activities, simulations, and real-world applications (Floor, 2018; Wong & Hughes, 2022). Lastly, LXD draws upon multiple disciplines to inform design decisions, considering factors such as psychology, cognitive science, sociology, and user experience (Floor, 2018; Weigel, 2015).

Therefore, LXD expands our understandings of learning experiences, providing instructors, designers, and researchers with the opportunity to empathize with learners and create experiences that enrich our repertoire of learning design strategies that can be implemented broadly As such, LXD broadens our definitions of what is to be considered a learning experience, affording instructors, designers, and researchers the opportunity to empathize with learners and develop experiences that expand our learning design toolbox (Ahn et al., 2019; Weigel, 2015). As technology continues to evolve and is leveraged in different ways to support teaching and learning, further research and practical applications of LXD are needed to enhance educational practices and meet the diverse needs of learners in various learning environments. Thus, in the context of this study, we implemented the LXD framework to implement a blended learning pedagogical approach that integrates interactive video-based mathematics learning for elementary students in the classroom.

Blended learning approach

Blended learning utilizes the combination of both online tools and face-to-face learning modalities such that learners complete some or all of the learning activities through technology-mediated instruction with thoughtful and intentional instructional design (Li et al., 2021; Müller & Mildenberger, 2021). More specifically, Garrison and Kanuka (2004) highlighted the critical importance of deploying blended approaches mediated by educational technologies in a face-to-face classroom context, stating that it was not a replacement for traditional in-person learning. Traditional learning typically takes the form of a teacher-centered approach where learners are passively listening, rather than actively participating, engaging, or participating as active agents in the learning experience (Li et al., 202 l; Kassab et al., 2019).

The blended learning approach attempts to shift the teaching and learning paradigm in a way that places more of an emphasis on student-centered active learning experiences while leveraging technologies (Tan & Hew, 2016). This hybrid model integrates the strengths of both modalities, offering flexibility, accessibility, and personalized learning experiences while retaining the benefits of direct interaction with instructors and peers (Niyomves et al., 2024; Singh et al., 2021; Wong et al., 2024). Research on blended learning approaches has shown that when compared to traditional learning, students who experienced blended learning performed better than their counterparts (Bernard et al., 2014; Means et al., 2013; Vo et al., 2017). In each of these studies, technology or online instruction was integrated with the face-to-face classroom context and was used as an instructional tool that was leveraged to support teaching and learning. As such, while blended learning approaches are not new to education, it has certainly garnered more attention with the recent adaptations to online learning modalities during the pandemic and the return to in-person instruction (Wong et al., 2023, 2024). Many instructors and educators want to take advantage of the pedagogical affordances of technology-mediated instruction and integrate aspects of blended learning into their classroom curriculum in this post-pandemic teaching and learning era (McCarty, 2020; Oyelude, 2022; Rapanta et al., 2021). Thus, this presents a unique opportunity to explore how adopting LXD and deploying blended learning experiences might support the changing technological landscape of classroom instruction.

Video-based learning as an instructional and research tool

Videos have been widely utilized as instructional tools to enhance both in-person and online learning experiences. Over the past three decades, educational technologies, including video and multimedia resources, have become essential components of teaching and learning, with their importance further amplified by the growth of online education (Cruse, 2006; Mayer, 2019; Wong et al., 2024). Previous research in elementary mathematics instruction, upon which this study builds, demonstrates that videos not only facilitate teaching and learning but also serve as a medium to support research activities by delivering consistent, standardized, and measurable learning experiences (Begolli & Richland, 2018; Mesghina et al., 2024; Richland et al., 2010; Wong et al., 2024). As a result, video-based learning provides a reliable platform for testing and experimenting with classroom strategies by offering instructional content that minimizes variability in teaching methods (Begolli & Richland, 2018). This consistency allows researchers and educators to evaluate the effectiveness of specific pedagogical approaches, analyze student outcomes in controlled environments, and refine teaching techniques to enhance learning experiences. Furthermore, the structured nature of video-based materials, when designed intentionally (Mayer, 2019; Wong et al., 2024), enables reproducibility in studies, making it easier to compare results across different classrooms and learning contexts.

Furthermore, past research highlights the many benefits of video-based learning, including its ability to reinforce lecture and reading materials, build foundational knowledge, enhance comprehension, accommodate diverse learning preferences, boost student motivation, and improve teaching effectiveness (Cruse, 2006; Kolas, 2015; Wong et al., 2023, 2024; Yousef et al., 2014). Additionally, video design features such as searchability, playback options, content retrieval, and interactivity are shown to enhance engagement and create more effective learning experiences (Giannakos, 2013; Yousef et al., 2014; Wong et al., 2023). For example, Wong et al. (2024) surveyed over 300 elementary students during the COVID-19 pandemic and found intentional online course design features such as asynchronous video formats and interactivity to be effective in increasing learners' engagement while reducing their mind-wandering. The flexibility of asynchronous videos allowed students to interact with course content at their own pace, accommodating varying learning styles (Wong et al., 2024). Building on these insights, this study integrates lessons learned from Wong et al. (2024) to redesign a mathematics course using a blended learning approach. By combining the strengths of video-based learning with in-person instruction, this blended format reimagines course delivery, leveraging video tools to provide consistent and flexible learning experiences while maintaining the benefits of face-to-face interaction. This approach aims to adapt effective strategies developed during remote learning in the COVID-19 era to enhance in-person educational contexts, increasing student engagement and fostering situational interest through the thoughtful integration of video-based tools and face-to-face interactions.

Theoretical framework

Engagement

Student engagement in the educational context refers to the active involvement and participation of students in learning activities that contribute to achieving desired outcomes (Hu & Kuh, 2002; Richardson & Newby, 2006). Engagement has been found to encompass

various dimensions, including attention, curiosity, interactivity, and interests exhibited by students during instructional units (Pellas, 2014). A growing body of research has recognized the significance of student engagement in predicting positive educational outcomes. Numerous studies have established a positive relationship between student engagement and various student outcomes (Fredricks & McColskey, 2012; Hamari et al., 2016; Sun & Rueda, 2012; Wong & Hughes, 2022; Wong et al., 2023). Bolliger and Halupa (2018) found that higher levels of engagement were associated with greater progress in learning, course satisfaction, and improved course grades. These findings emphasize the importance of student engagement as a key factor contributing to positive learning outcomes, which may play a significant role in blended learning environments.

Several factors have been identified as influential in shaping student engagement. Quality instructional design has been recognized as a critical element in fostering student engagement in online learning environments (Marrongelle et al., 2013; Pappas, 2015). According to Hidi and Renninger (2006), student engagement can be enhanced when learners demonstrate their interests and are given a certain level of autonomy in their learning tasks. Additionally, motivational factors such as students' interests, task-value, and self-efficacy have been found to impact student engagement levels during the learning process (Chen et al., 2010; Sun et al., 2012; Wong et al., 2023). Conversely, studies have shown that negative learning experiences can arise when learning interfaces are difficult to navigate, uninteresting, or unengaging (Hidi & Renninger, 2006; Hughes-Roberts et al., 2019). Moreover, the integration of multimedia elements has been shown to enhance student engagement and motivation. Mayer (2014) highlighted the cognitive theory of multimedia learning, which suggests that multimedia resources, such as videos, interactive simulations, and gamification techniques, can stimulate engagement and improve learning outcomes (Sailer et al., 2017). This highlights the importance of intentional design choices that maximize student participation, interactivity, and user experience to support their engagement throughout the learning experience. By understanding and incorporating these factors into educational practices, educators and instructional designers can promote active participation and enhance student engagement to optimize student learning outcomes. Thus, the current study implemented intentional design choices to maximize students' participation and degree of interactivity by ensuring quality instructional design that would foster students' interests and user experience, to support their engagement throughout the learning experience.

Situational interest

Situational interest refers to spontaneous interest that can be "environmentally activated," often during or because of a novel aspect introduced while learning (Schraw & Lehman, 2001). Schraw and Lehman (2001) also argued that promoting students' SI while learning increases their intrinsic motivations and boosts the number of learning strategies utilized during the learning process. This suggests that SI is malleable and can be increased given the learning environment and factors of the immediate task at hand. Past research also indicates that SI is a strong motivator for sustaining learner participation and interaction throughout the entire learning process (Chen et al., 2001). As such, students' SI is a powerful tool that can be changed and leveraged by instructors in order to foster and maintain student engagement in learning. While SI and student engagement have been widely evaluated in the context of in-person learning activities (Sun et al., 2012), less is understood about how to facilitate SI for young students in blended learning environments.

Building on Schraw et al.'s (2001) suggestions for promoting situational interest in the lesson, we intentionally designed the blended learning environment to offer meaningful choices to students that aimed to foster students' self-determination. We also designed the platform with careful user experience design to ensure well-organized, vivid texts that are intended to activate students' prior knowledge, provide rich visual representations that align with key concepts, and coherence in subject matter to increase comprehension (Mayer, 2019; McKeown et al., 1992; Schraw et al., 2001). Lastly, this blended course encouraged students to be active learners and consistently engage in meaningful learning experiences as the learning design intentionally embedded opportunities for elaboration, critical thinking, and rehearsal (Loxterman, 1994; Schraw et al., 2001; Wong et al., 2022). Thus, this study examines how our intentional design choices integrating technology to enhance teaching and learning might influence young students' SI and foster engagement during blended learning.

User experience

Lastly, we explored students' user experience (UX), as it is considered a key contributor to students' success in online learning environments and has been shown to increase student engagement (Pellas, 2014; Wong et al., 2022). As SI refers to the interest activated by the learning environment, user experience can be seen as a measure linking the learner's experience on a specific learning interface and their interest in learning as a result of utilizing this medium. Broadly defined, user experience is "the extent to which a product can be utilized by specified users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241–11, 1998). In practice, UX refers to the effectiveness of the learning interface and whether or not a student can successfully interact with the course platform to accomplish an intended task.

The literature shows that learners spending more time worrying about accessing, locating, and finding course content within the user interface are likely to experience greater frustration and confusion within an online learning environment (Hu, 2008; Shneiderman & Hochheiser, 2001). Learning environments with strong UX redirect students' efforts toward learning the concepts, rather than learning how to access the content. In elementary education, this allows young learners to focus their attention on the teaching and learning taking place, rather than allowing the edtech tool to present itself as a barrier to learning. Taking this into consideration as researchers and instructors, this shifts the perspective from focusing solely on instruction to also considering the deep understandings of learners — what they need, what they value, what impacts their abilities and interests, and the implications of the learning interface. As such, UX aims to create a positive student learning experience through content accessibility, interest, and design, all of which are significant predictors of student engagement in both online and in-person learning environments (Thomson & Lynch, 2003).

Cognitive apprenticeship model

To facilitate students' interests and enhance the pedagogical design of the blended learning experience as students transitioned from distance learning to the classroom, the cognitive apprenticeship model (CAM) was selected (Ghefaili, 2003). CAM is founded on the principle that learning is best achieved through active engagement and practical application,

emphasizing the inseparable connection between learning and doing (Brown et al., 1989). By adopting CAM, the aim was to create immersive learning environments that simulate real-life settings, enabling learners to acquire and apply new knowledge and skills in relevant contexts while leveraging educational technologies.

Key components of the CAM framework include content knowledge, modeling, coaching, scaffolding, articulation, reflection, and exploration (Brown et al., 1989; Collins et al., 1989). Content knowledge refers to the domain-specific information and skills that learners need to acquire (Collins et al., 1989). Modeling involves expert demonstrations of tasks or processes to provide learners with cognitive templates for successful performance (Brown et al., 1989). Coaching involves providing guidance, feedback, and support to learners as they engage in learning activities (Collins et al., 1989). Scaffolding refers to the provision of temporary support and structure to learners as they gradually develop competence (Collins et al., 1989). Articulation encourages learners to express their understanding and reasoning processes, facilitating metacognition (Brown et al., 1989). Reflection promotes learners' critical thinking and self-evaluation of their learning experiences. Lastly, exploration encourages learners to actively explore and apply their knowledge and skills in authentic settings (Collins et al., 1989). To bring the principles of the cognitive apprenticeship model (CAM) to life, pre-recorded videos of authentic math lessons taught by an instructor in a real classroom setting are utilized. These videos reflect a realistic classroom context by capturing natural student–teacher interactions, which provide students with bite-sized segments of authentic classroom experiences to include the elements of CAM (e.g. which include modeling, coaching, scaffolding, articulation, reflection, and exploration) are embedded to create meaningful and engaging learning opportunities (Drijvers, 2019; Pappas, 2015; O'Brien & Battista, 2020). Similar to Begolli and Richland (2016) and Wong et al. (2024), students engage with immersive video-based learning, observing real classroom interactions and participating in scaffolded problem-solving activities designed to reinforce the concepts presented. They are encouraged to immediately apply their learning by tackling these problem scenarios and reflecting on their approaches, which have been found to foster interests, enjoyment, higher-order thinking, and active engagement (Schraw & Lehman, 2001; Sun & Rueda, 2012; Wong et al., 2024).

To enhance the use of CAM, we adopted Mayer's (2020) multimedia learning principles, which are integrated throughout the video design to provide evidence-based strategies to enhance comprehension and retention. Segmenting divides lengthy videos into manageable sections, coherence is maintained by aligning visuals with lesson instructions, prompts, and problem statements, and signaling uses visual cues and gestures to guide students' attention to key content (Mayer, 2020). Additionally, the pre-training principle introduces foundational concepts, definitions, and mathematical strategies to ensure learners are prepared to engage with the material (Mayer, 2020; Richland et al., 2009). By integrating these multimedia design principles with interactive elements such as modeling and scaffolding, the video-based blended learning approach effectively mirrors real-world classroom dynamics, enhancing ecological validity (Begolli & Richland, 2018; Clarke et al., 2018). This synergy between CAM and Mayer's multimedia principles establishes a robust theoretical foundation for the LXD-based blended course, seamlessly combining educational technologies with strategies that foster meaningful and authentic learning experiences in classroom settings.

Current study

Traditionally, young students have been accustomed to learning in formal, face-to-face classroom environments (Begolli & Richland, 2016; Leander et al., 2010; Richland et al., 2017). However, the abrupt shift to remote learning during the pandemic introduced a completely new learning landscape, presenting young learners with unfamiliar challenges related to educational technologies. Students have had to adapt to various "edtech tools" that were employed to facilitate teaching and learning, often requiring them to embrace new modes of learning and confront unforeseen obstacles (Agarwal & Kaushik, 2020; Wong & Hughes, 2023; Wong et al., 2022). Educators are exploring ways to integrate the previously utilized technology platforms into the traditional classroom setting, capitalizing on the advantages offered by these educational tools. Building on insights from a beta version of an online course implemented during the peak of the COVID-19 pandemic (Wong et al., 2021, 2024), we applied the LXD framework to guide iterative design revisions informed by student feedback, with the goal of optimizing the blended learning experience for children in the current study. When developing and introducing a new blended course for young students, it is essential to assess the impact of teaching and learning methods on children's overall learning experiences.

In this design-based research study, we apply quality instructional design as a lever to support students' situational interest and ensure strong user experience design to alleviate technical worries related to blended learning. We then further explored the combination of situational interest and user experience predicting students' engagement. To this end, we tested the efficacy of our LXD efforts to examine whether the video-based math lesson supported or hindered young students' engagement during blended learning. This study is guided by the following research questions:

1. To what extent does students' Situational Interest (SI) influence their perceived learning engagement (PLE) while learning math through a blended learning experience?
2. To what extent does students' User Experience (UX) predict their perceived learning engagement (PLE) while learning math in a blended learning environment?
3. How effectively did the Learning Experience Design (LXD) and User Experience Design (UXD) support students' blended learning experiences?

Methodology

Participants

We recruited 5th and 6th-grade teachers from two Southern California school districts. Of the ($n = 305$) students who participated, 50.8% identified as female and 42.3% identified as male (Table 1). This sample consisted of children from a variety of racial and ethnic backgrounds (31.7% White, 3.6% Black, 20% Asian, 13.6% Hispanic, 21.3% other).

Procedure

The current study consisted of three parts taking place on three separate days over the course of two weeks. Participation in this study took place in 5th and 6th-grade classrooms,

Table 1 Participant demographics

Variable	N	Percent (%)
Gender		
Female	155	50.8
Male	129	42.3
Other	10	3.3
Prefer not to say	11	3.5
Ethnicity		
Black	14	3.6
Asian	77	20.0
Hispanic	42	13.6
Native American	11	2.9
White	122	31.7
Other	82	21.3
Age		
9 yo	11	3.7
10 yo	44	14.6
11 yo	116	38.5
12 yo	125	41.5
13 yo	4	1.3
14	1	0.3

This table includes all participants who achieved a progress score of 68% or higher. Ethnicity percentages total more than 100% because respondents were permitted to select multiple racial categories

in which students participated as part of their math class instruction for the day. The blended math lesson intervention was originally modeled after Begolli et al. (2016) and Richland et al. (2017) and was later redesigned for online learning by Wong et al. (2024). The current design features an interactive video-based math lesson that was pre-recorded and split into two parts. The 2-part lesson was introduced to students in the classroom over the course of the first two study visits.

Table 2 details the study procedure breakdown. Day 1 of the study began with a pre-test administered to all students, followed by the first part of the math lesson intervention, which students watched and completed on their individual laptops with headphones. One to two school days later, on Day 2 of the study, students continued individually with the second part of the math lesson intervention on their laptops and then completed an immediate post-test assessment to measure the learning outcome from the two-day math lesson. Five to seven days later, on Day 3, a delayed post-test assessment was administered, along with additional surveys to measure students' learning experience with the math lesson intervention.

Design-based Research Phases

This study represents a part of a long-term, iterative design-based research (DBR) initiative aimed at evaluating instructional tools and prototypes in ecologically valid, real-world settings, guided by learning theories (DBR Collective, 2003; Siek et al., 2014). Over the course of several years, we have iteratively designed, tested, refined, and redeployed

Table 2 Study procedure breakdown

Day 1	• Pre-test assessment is administered • Intervention – Math Lesson Part 1 completed in the classroom on a laptop
Day 2	• Intervention – Math Lesson Part 2 completed in the classroom on laptops • Post-test assessment is administered
Day 3	• Delayed post-test assessment is administered • Students complete a survey administered via Qualtrics XM, including the following instruments: – Perceived Learning Engagement (PLE) – Situational Interest Scale (SI) – Standardized User Experience Percentile Rank Questionnaire (SUPR-Q)

instructional courses to improve elementary math instruction with video-based learning (Begolli & Richland, 2018; Wong et al., 2021, 2024). The DBR methodology was selected to enable incremental iterations and continuous improvement of instructional tools within authentic environments, ensuring they effectively enhance student learning experiences (Scott et al., 2020). This iterative process ensured continual enhancement of the instructional courses, guided by empirical evaluation and critical reflection. This process adhered to the four-step DBR framework proposed by Scott et al. (2020), which includes:

1. Designed instructional tools based on learning theories to address specific educational challenges.
2. Tested these tools in classrooms to evaluate their effectiveness.
3. Evaluated the tools' impact on student learning and the broader learning environment.
4. Reflected on the outcomes and implementation process, iteratively refining the tools for improved efficacy.

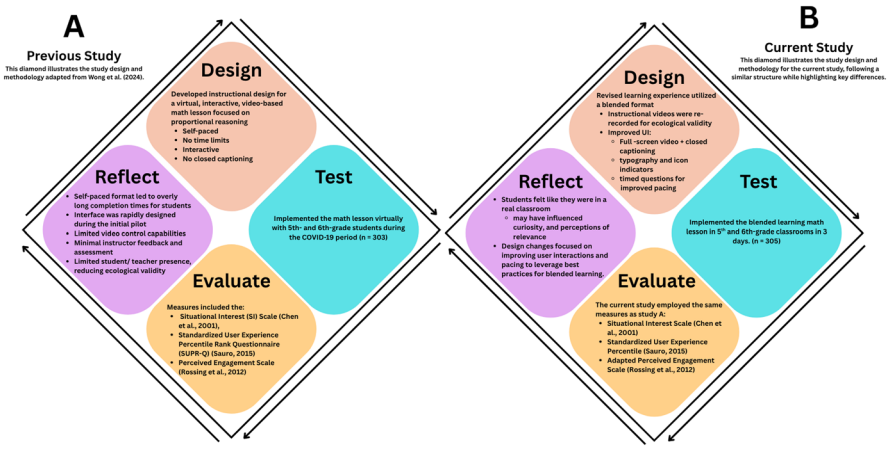

Fig. 1 depicts two DBR cycles represented as a double-diamond process. Findings from the prior study informed targeted design revisions in the current study, including improvements to ecological validity, instructional pacing, user experience design, accessibility, and student–teacher presence

Building on previous iterations of this study (Begolli et al., 2016; Richland et al., 2017), which identified limitations such as outdated interfaces, low video quality, and the need for new mathematics lessons aligned with Common Core Standards, we evaluated these constraints (Richland et al., 2017) and developed a fully online, asynchronous course during the COVID-19 pandemic (Mesghina et al., 2024; Wong et al., 2024) (see Fig. 1). This version introduced interactivity and self-paced learning, yet it faced challenges in maintaining experimental control due to the learning management system granting unlimited time for students to complete lessons and replay video segments. While these conditions were advantageous for online learning during the COVID transition to distance education, they were less ideal for both experimental control and the classroom time constraints that accompanied a return to in-person learning.

As a result, we began by designing a new learning interface for the blended math lesson intervention guided by LXD principles. This new design incorporated interactive learning engagement opportunities with standardized time allowance for answering questions and limited video-control capabilities, enhancing engagement while addressing challenges related to inconsistent learning durations and classroom time management. For example, students were only able to pause videos (i.e., if they left the classroom for a bathroom break), ensuring they would not miss any intervention content, but they were not able to playback or restart video lesson segments. Next, during the Testing phase, the redesigned blended-learning course was implemented in classroom settings, marking a return to in-person research after the transition to online learning during the COVID-19 pandemic. Improvements, such as controlling time spent on videos and standardizing time spent on self-paced, interactive learning engagement segments, allowed for more consistent learning conditions and streamlined classroom management. In the Evaluation phase, we assessed the effectiveness of these LXD-based tools using a cross-sectional survey design (Craig et al., 2012), collecting both structured survey responses and open-ended feedback from students about their experiences in the blended learning environment. Finally, during the Reflection phase, a retrospective analysis was conducted to examine how the redesigned course addressed limitations identified in earlier studies (Begolli & Richland, 2018) and to uncover the mechanisms driving the effectiveness of the LXD approach. These reflections informed further refinements to improve both the instructional tools and experimental rigor in future iterations.

Learning experience design of the math lesson

Mathematical Context: We build on the teaching with analogies (TWA) pedagogical approaches implemented by Richland et al. (2017) to support students' higher-order thinking skills by intentionally designing a math lesson targeted at teaching upper elementary students multiple strategies for solving proportional reasoning word problems. The objective of our video-based math lesson was to increase students' ability to flexibly utilize proportional reasoning strategies when solving math problems (Glynn, 2004; Zhao et al., 2025). Furthermore, the lesson sought to enhance students' conceptual grasp by elucidating the foundational principles and relationships inherent in the problems. It also aimed to promote procedural adaptability, enabling students to utilize various problem-solving approaches when addressing proportion-related challenges (Wong et al., 2024). This was done by embedding opportunities for students to compare alternative procedures and solutions, an intentional math instructional design feature shown to better engage students,

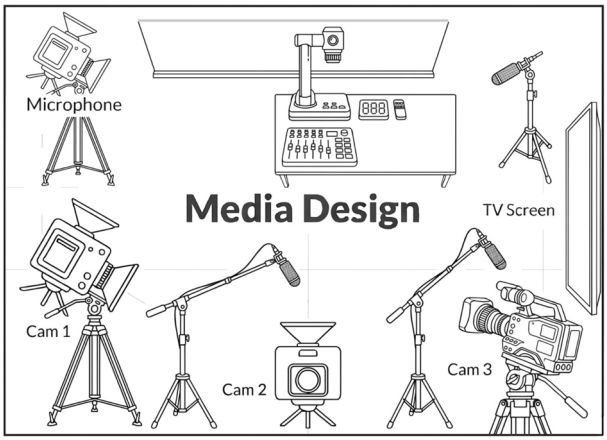

Fig. 2 This figure maps the video equipment configuration during the live production of the instructional video(s)

refine initial understandings, and foster deeper conceptual understanding (Begolli et al., 2014; Richland et al., 2017; Wong et al., 2024).

The lesson design employed a reform-based instructional model in which the teacher first asks the students to solve a new proportional reasoning problem independently, prior to receiving explicit instruction (Schwartz et al., 2011) (See Supplemental Materials). Next, the teacher chose students to come to the board and describe their strategy in front of the entire class. Subsequently, the teacher led a discussion on each mathematical approach and engaged in a higher-level conceptual overview of each respective target strategy: the multiplication equations strategy, double number line strategy, and equivalent fraction strategy. During the conceptual overview phase, the instructor made use of specific pedagogical approaches that offered support to students' relational reasoning. Specifically, the instructor introduced alternative solution strategies for each problem, made visible representations of different solution strategies available simultaneously, and used intentional spatial organization for solutions to highlight key mathematical relations.

Video Design: The videos were recorded as a live, semi-scripted lesson on proportional reasoning. Utilizing newly accessible 4 K multi-camera video production technologies, one camera focused on the teacher, the second camera captured the teacher and the whiteboards, the third camera captured a wide-angle view of the students, and the fourth camera served as a document camera, which showed the teacher's live written work (See Fig. 2). 360-degree microphone arrays were placed around the classroom to capture student audio at each of their desks. To view the media design in action, click on the video link in the supplementary materials (Supp. Materials Video), which shows the behind-the-scenes recording process.

Final Cut Pro X was used for post-production to edit the multi-camera workflows. This video design approach builds off of Begolli et al. (2016) and was chosen explicitly to display student and teacher interactions occurring in the everyday classroom with real students, establishing a natural learning context, while also directing students' attention to specific camera angles for increased engagement. Selecting this video-design approach also enabled instructional stimuli to have high ecological validity, reflecting the stimuli that children in the live lesson would naturally be attending to at various

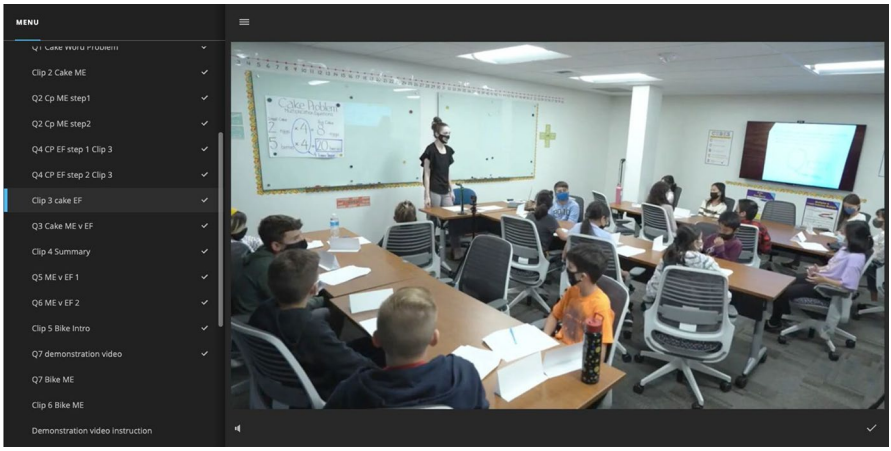

Fig. 3 This figure shows the blended course interface design and how the navigation, usability descriptions, and video were easily accessible to students

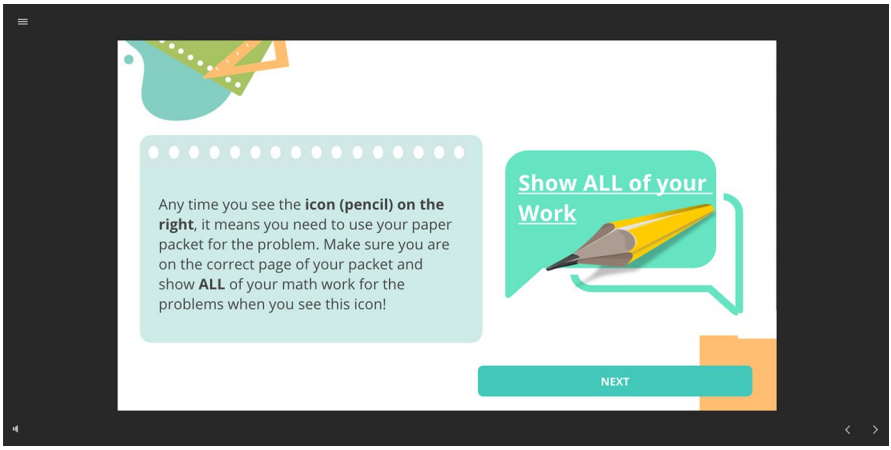

Fig. 4 This figure shows the consistent vectors, instructions, and standardized buttons that were used to guide learners through the course

points in the lesson (e.g., whiteboard versus a student answering a question), while maintaining experimental control (Begolli & Richland, 2016; Richland et al., 2018).

Blended Learning Lesson: The blended lesson was developed using Articulate 360, a suite of e-learning authoring applications used to create professional end-to-end interactive learning experiences. Cognizant of the research behind effective LXD and to implement the CAM pedagogical framework, an hour-long video lesson was segmented into ten parts instead of one continuous stream to reduce fatigue, cognitive load, and opportunities for students to mind wander (Mayer, 2019; Wong et al., 2024). After watching a video segment, learners would engage in embedded practice problems with worked examples as opportunities for students to practice hands-on with the lesson content, allowing them to crystallize the different solution strategies prior to moving on to the next problem. Problem solving with worked examples scaffolds novice learners

by drawing attention to the structural similarities in the strategies to ensure students attend to the key ideas, concepts, and relationships in practice (Richland & Simms, 2015). Lastly, free-response questions were embedded for students to engage in reflections about "how and why" they arrived at their final solution, diving deeper into their justification for why one strategy solution may have been more effective than another.

By emphasizing practice and reflection during instructional time, not only during evaluation, these pedagogical design choices served as low-stakes content practice and retention exercises for learners to verify their accuracy while developing conceptual understanding. Additionally, these design choices aimed to foster a student-centered learning experience that maximized the learning time with active learning activities to garner students' interest in the course itself and boost levels of engagement with the video lesson (Tullis & Benjamin, 2011; Wong & Hughes, 2022).

User Experience Design: In designing the blended course, careful considerations were made to ensure that the course design system interface adhered to standardized usability heuristics for UX design (Gonzalez-Holland et al., 2017; Nielsen, 2005). For example, to create "aesthetic and minimalist designs," the interface for the video and image placements was unobtrusive, taking up most of the screen (See Fig. 3).

The color palette avoided bright colors and kept to three main colors and some variations of those three colors for highlighting and recognition purposes. Furthermore, to lighten the user's memory load and provide ease of use, we created vectors and used typographical emphasis in a consistent manner. We created a "show all of your work" icon (See Fig. 4) and placed it on all interfaces that required students to show their work in a provided paper packet.

To further the process of recognition and findability, all interfaces of the course had similar placements of information (e.g., instructions were always placed in a yellow box above the mathematical problem that was always in a blue-green box). The use of bolding, italicizing, and underlining text was consistent throughout the course. Additionally, we incorporated the use of animations, time triggers, reminders, and audio narrations to guide users and mimic the pacing of a classroom, while the course roadmap allowed for

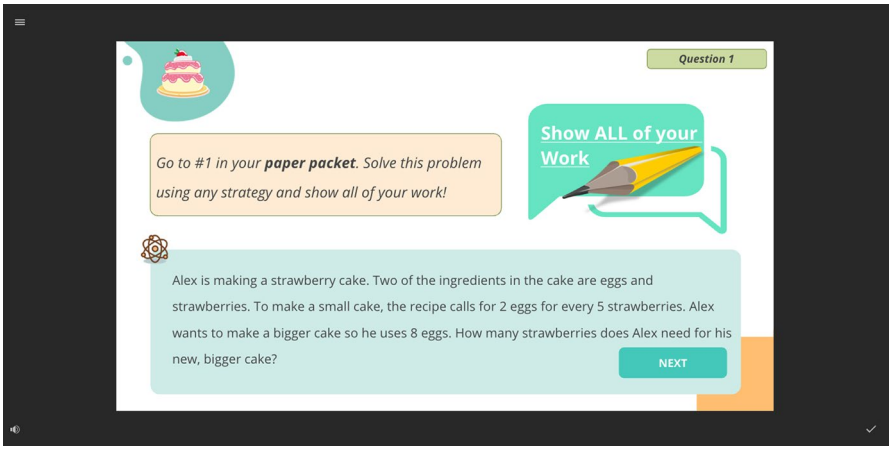

Fig. 5 This figure shows the accessibility features provided to students, such as the time trigger, audio narrations, and instructional reminders

findability and accessibility (See Fig. 5). Collectively, these intuitive design choices mitigated visual complexities and technical difficulties, allowing users to focus on the task at hand.

Data sources

Data in this study were collected both electronically and on paper. All of the measures employed were distributed to participating students either online via Qualtrics XM or paper packets. Students' pre- and post-assessments were administered and collected using hard copy paper packets, reflecting standard in-person math test procedures, allowing for students to show all of their work while solving problems. The math assessments used in this study were researcher-developed in collaboration with the teaching instructor as part of the course lesson plans (Wong et al., 2024; Zhao et al., 2025) and were aligned with Common Core State Standards (CCSS) for proportional reasoning, including equivalent fractions (5.NF.B.3) and unit ratio reasoning (6.RP.A.1–6.RP.A.3) (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010). In those studies, the math assessments demonstrated acceptable internal consistency reliability (e.g., Cronbach's $\alpha = 0.77$ across posttest time points) and sensitivity to instructional manipulations (Zhao et al., 2025). While learners completed these assessments, they were a supplementary outcome measure and not included in the study measures, as the primary focus of this study was the learning experience and perceived engagement with the course design rather than math performance (See Supplementary Materials). All other surveys, including basic demographic information, were collected online through Qualtrics XM immediately after engagement in the two-day-long online higher-order thinking (HOT) math intervention to ensure quality and robustness of student responses. Participants were provided a direct link to the surveys, which were embedded within the online math course that was hosted on Articulate RISE. Students were asked to reflect on their experiences completing the intervention.

This study primarily focused on examining students' survey measures about their blended learning experiences through three constructs: perceived engagement, user experience, and situational interest. To address our research questions and objectives of examining the impact of implementing the pedagogical paradigm of Learning Experience Design (LXD) on students' online math learning experiences, we conducted a comprehensive review of the literature to identify appropriate survey instruments guided by specific criteria. Notably, there is a limited body of research that examines our variables of interest in the context of elementary blended math education.

Students' perceived learning engagement was measured using 5 out of the 12-item survey by Rossing et al. (2012). To ensure each measure's reliability, the number of questions and their structure were preserved without alteration. However, minor contextual modifications were made, such as replacing the term "classroom" with "online activity" to align with the context of the blended math intervention examined in this study. Sample items include: "The online activity motivated me to learn math more than a regular classroom lesson" and "The online activity made me feel like I am good at math compared to doing math in the classroom." Response options were designated on a 5-point scale, 1 (completely disagree) to 5 (completely agree). The internal consistency coefficient (Cronbach alpha) for this instrument is. 84. Additionally, smiley face emojis were incorporated into the anchors of each survey questionnaire to facilitate students' ability to assess their responses. This approach has been demonstrated to be effective

Table 3 Descriptive Statistics and Cronbach's Alpha of Measures

Scale	No. of items	Alpha	Min	Max	*M*	*SD*
Perceived engagement	5	.84	1.00	5.00	3.23	.89
Situational interest	14	.93	1.29	5.00	3.47	.74
User experience (SUPR-Q)	8	.87	1.57	5.00	3.91	.68

for children and young adolescents as an adjunctive rating scale in quantitative survey evaluations (Hall et al., 2016; Savage, 2018).

The Standardized User Experience Percentile Rank Questionnaire (SUPR-Q) was used to measure students' user experience within the course platform (Sauro, 2015). This instrument is a standardized questionnaire consisting of 8 items commonly used in the fields of User Experience (UX) to assess users' perceptions across four key aspects of a website or interface: usability, trust and credibility, appearance, and loyalty. Example statements include "I found the website to be good looking (attractive)" and "The website looks clean and simple." Response options were designated on a 5-point scale, 1 (completely disagree) to 5 (completely agree). The internal consistency coefficient (Cronbach's alpha) for this instrument is .87.

Students' situational interests were measured using the Situational Interest Scale (Chen et al., 2001). The survey measured students' levels of interest while participating in the lesson. Survey items include statements like: "What I learned in the math lesson is fascinating to me" and "What I learned in the math lesson can be applied to real life." Response options were designated on a 5-point scale, 1 (completely disagree) to 5 (completely agree). The internal consistency coefficient (Cronbach's alpha) for this instrument is .93.

Lastly, open-ended, free-response questions were included in the survey to give students the opportunity to share their thoughts, feelings, reactions, and attitudes after participating in the blended math learning experience. Students responded to three different questions: "What do you like about the course?" "What do you not like about the course?" and "What would you improve?" Data from this section of the survey were examined using thematic analysis to understand what students found to be challenges and successes of the course design.

Data analysis

To ensure the validity and reliability of the instruments used in this study, descriptive statistics and scale reliability checks were performed. This involved calculating the alpha coefficients for each validated instrument, as detailed in Table 3. In order to analyze the variables, the Likert-scale responses were recoded into their appropriate numerical values. Subsequently, the means of the items corresponding to each subscale were computed (see Table 3). Bivariate correlation analyses were then carried out to examine the relationships between students' situational interest (SI), user experience (UX), and their course engagement, with the results presented in Table 4. Finally, multiple regression analyses were utilized to assess the predictive role of students' situational interest and user experience in determining their level of course engagement, as shown in Table 5.

For the qualitative analysis of student evaluation responses, the data were analyzed using the Qualtrics Research Core XM text analysis software. A deductive coding

Table 4 Pearson's correlations

Variable		Situational interest	User experience	Perceived learning engagement
1. SI	n	–		
	Pearson's r	–		
	p-value	–		
2. User experience	n	295	–	
	Pearson's r	.621***	–	
	p-value	< .001	–	
3. PLE	n	294	296	–
	Pearson's r	.613***	.521***	–
	p-value	< .001	< .001	–

* $p < .05$, ** $p < .01$, *** $p < .001$

approach, also known as concept-driven coding (Saldaña, 2021), was employed to examine students' open-ended responses to the post-assessment questionnaire. This method was chosen to ensure the validity and reliability of the findings by focusing on predetermined themes based on the quantitative variables observed in the study. The coding process involved creating analytic memos and developing both subcodes and anchor codes, which were systematically applied in alignment with the key variables identified in the quantitative analysis (see Table 6). Each code application was carefully defined with clear, inclusive, and exclusive statements to maintain consistency and accuracy in the coding process. After the initial coding, the results were triangulated by comparing and corroborating the qualitative and quantitative findings. This helped identify overarching patterns and insights that emerged from both types of data. To ensure the reliability and reduce potential bias during the coding process, the research team employed a spot-checking strategy, periodically reviewing the coded data to confirm consistency and accuracy. This approach helped enhance the credibility of the analysis and ensure that the interpretations were grounded in both qualitative and quantitative evidence.

Quantitative results

The quantitative analysis of this study reveals significant relationships among situational interest (SI), user experience (UX), and perceived learning engagement (PLE) in the context of an elementary blended math learning environment. The Pearson correlation results presented in Table 4 and Fig. 6 reveal a significant and moderate positive correlation between students' SI and PLE ($r = .613$, $p < .001$) (See Fig. 6). This suggests that as students' SI increases, their engagement with their PLE also tends to improve, indicating that heightened situational interest may positively influence students' learning environments.

Similarly, a significant and moderate positive correlation was observed between SI and students' UX (r (295) = .621, $p < .001$). This indicates that students who report higher levels of situational interest also tend to have better overall experiences with the platforms or tools used in their learning environments. Additionally, there was a significant moderate association between students' PLE and their UX (r (296) = .521, $p < .001$), suggesting that

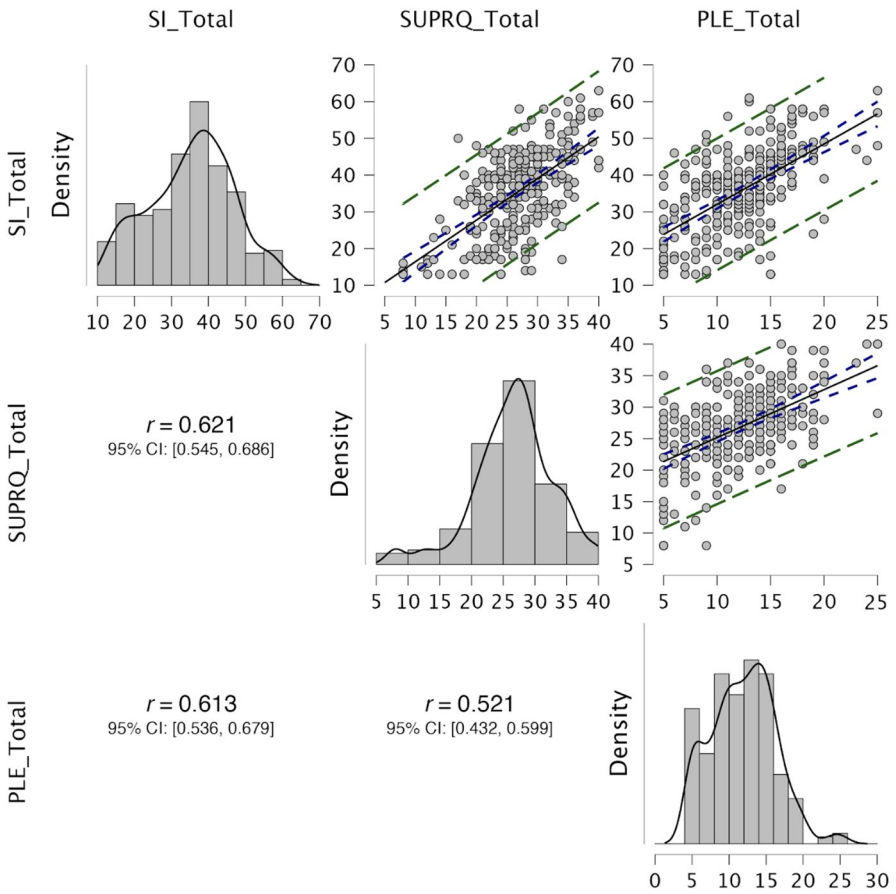

Fig. 6 This figure shows the correlation matrix of the study variables

students who engage more effectively with their personal learning environments are also likely to report more positive user experiences.

To further explore the impact of SI on students' PLE, multiple regression analyses were conducted with PLE scores as the outcome variable, as shown in Table 5. The regression results indicated a significant positive effect of students' SI on their PLE ($\beta = .471$, $p < .001$), suggesting that higher levels of situational interest contribute significantly to better engagement with students' personal learning environments. Furthermore, a significant positive effect was observed for students' UX scores on PLE ($\beta = .227$, $p < .001$), suggesting that improvements in students' user experiences also positively affect their engagement with learning environments. Together, students' SI and UX accounted for 40.7% of the variance in PLE, as indicated by the model's R-squared value ($R^2 = .407$). The results of the ANOVA further indicate that the overall regression model was highly significant ($F(2, 291) = 99.84$, $p < .001$), showing a strong explanatory power of these two factors in predicting students' perceived learning engagement. These findings highlight the important role of both situational interest and user experience in shaping students' learning environments and underscore the need to consider these factors when designing educational experiences.

Table 5 Multiple regression analysis predicting children's online engagement

Model	Variable	Unstandardized	Standard error	Standardized	t	*p*
H_1	(Intercept)	1.619	.850		1.904	.058
	Situational interests (SI)	0.176	.022	.471	8.180	< .001
	User experience (SUPRQ)	0.155	.039	.227	3.939	< .001

*p < .05, ** p < .01, *** p < .001

Qualitative results

A thematic analysis of students' open-ended responses identified four key themes that shed light on their learning experiences: (1) Learning experience design enhanced students' engagement, (2) The teacher's use of multiple solution strategies as a pedagogical technique, (3) The user experience of the online course influenced students' learning experience, and (4) The LXD of the course revealed several key design facets for iterative improvement (See Table 6).

Theme 1: Learning experience design enhanced students' engagement.

LXD was defined as references to the pedagogical learning design frameworks and the curriculum instruction implemented throughout the online course. More specifically, these were direct references to pedagogical design, video design, the scaffolding of key concepts, real-world context, and the applicability of instructional strategies.

> *Student A:* "I liked that the lessons were thorough and easy to follow along to. I also liked how there were students in the video, so it felt like you were really in the classroom with them. It also makes the lessons feel a little more human and comforting."
> *Student B:* "I liked that I learned new strategies and techniques in math that may help me in the present and future."
> *Student C:* "I liked how it explained different strategies and got real responses by real students."

Theme 2: The teacher's use of multiple solution strategies as a pedagogical technique.

Providing students with multiple solution strategies is crucial for fostering deep conceptual understanding and developing flexibility within mathematics. The use of different strategies was defined as a pedagogical technique to teach students several alternative methods as tools to help children understand how to arrive at the same mathematically accurate answer using different approaches. More specifically, these were direct references of students mentioning the use of different source examples, multiple representations of the same problem, visual representations, and alternative solution strategies.

> *Student D*: "I really liked how they used many examples to explain one type of problem instead of only using one. The teacher let other students go up to the board and show how they did the work. I was able to understand it better than I would have been able to if I didn't see many examples."
> *Student E*: "I liked how…she went over the problem multiple times with different strategies."

Table 6 Unit of analysis: What did you like or not like about the online course?

Analytic category: Learning experience design enhanced students' engagement		
Codes	Definitions	Example
Learning design · Real-life · Multiple strategies · Comfort	References to the learning design, pedagogy, and the facilitation of the curriculum instruction Real life: references to the real-life teacher, students, and actual classroom of the video lesson Comfort: references to the relief and comfort that the online course affords *Inclusion: include any references that focus specifically on the pedagogical learning aspects of the VR lesson* *Exclusion: exclude if not mentioned in the context of learning design, pedagogy, and lesson activities*	I liked that the lessons were thorough and easy to follow along to. I also liked how there were students in the video so it felt like you were really in the classroom with them. It also makes the lessons feel a little more human and comforting I liked that I learned more about how to solve this and what to do in real life in this situation I liked that it was like you were in a classroom while you do the video. I understood a lot which helped me a lot with the questions being asked I really liked how they used many examples to explain one type of problem instead of only using one. The teacher let other students go up to the board and show how they did the work. I was able to understand it better than i would have been able to if I didn't see many examples I liked how Mrs. Marland found different strategies to answer the same questions It was easy to use and see the teacher explain everything clearly and showing different strategies I liked that on the online learning activity I was able to do the math at my own pace and pause it if I needed to I liked that if I got a question wrong I wouldn't feel bad cause no one would know

Table 6 (continued)

Analytic category: Learning experience design enhanced students' engagement		
Codes	Definitions	Example
Videos · Easy to follow · Interests · Multi-camera	References to the video, the video design, and the quality of the videos Easy to follow: references to how the lesson sequence, content scaffolding, video transitions, and ability to pause Interest: references to how students interests, curiosity, and active involvement were peaked by the video math lesson Multi-camera: references to the camera movements, jump cuts, and switches between the teacher, board, and student responses *Inclusion: include any references that focus specifically on the video, video design, and video interactivity* *Exclusion: exclude if referencing video in the context of UX design*	I liked the videos, this made me pay extra attention. Another thing I liked was that Ms. Marland explained the work and topic good I liked that the videos were short and simple and explained what the question and answer was I liked that on the online learning activity I was able to do the math at my own pace and pause it if i needed to I liked how the shots were taken where I can see the students and the teachers. I also liked how students came up to the desk and talked I liked how the video described all the strategies thoroughly. Another thing, I liked was that it was simple and not to hard to use or go through. Lastly, it was enjoyable to learn new math strategies
Analytic category: The teacher's use of multiple solution strategies as a pedagogical technique		
Codes	Definitions	Example
Different Strategies · Use of examples · Multiple representations · Alternative solutions	References to the use of different strategies for solving a mathematics problem Use of examples: references to the use of examples to explain a math problem Multiple representations: the use of two or more strategies present or available at the same time during the lesson Alternative solutions: the presentation of alternative mathematical options presented for students to decide which approach to utilize *Inclusion: include any references that focus specifically on the use of different strategies and examples to solve a mathematics problem* *Exclusion: exclude if not referencing to lesson content specifically*	I liked that I learned new strategies and techniques in math that may help me in the present and future. It was also kind of fun and worth it, not only cause of the party I really liked how they used many examples to explain one type of problem instead of only using one. The teacher let other students go up to the board and show how they did the work. I was able to understand it better than i would have been able to if I didn't see many examples I liked that it taught us to solve one problem in several ways I liked how it was easy to use and how it helped me learn new strategies in math. For example the number line and the fractions I liked how it described all the strategies thoroughly. Another thing, I liked was that it was simple and not to hard to use or go through. Lastly, it was enjoyable to learn new math strategies

Table 6 (continued)

Analytic category: The user experience of the online course influenced students' learning experience		
Codes	Definitions	Example
User experience Subcode: · Easy to use and navigate · Simplicity · Interactivity	Reference to the interface, navigation, ease of use as a result of the layout, design, and interactive elements of the online course User experience: navigation: references to navigability, ease or difficulty of use of the interface User experience: design: mentions of design, aesthetics, non pedagogical information layouts, color, the layout of modules of materials User experience: interactivity: mentions of dynamic elements, buttons, use of narration *Include: include if referencing Storyline 360 layout, interface aesthetic, navigability, click accessibility, ease of use* *Exclusion: don't include pedagogical lesson structure, the scaffolding of videos, instructional strategies*	I liked how there weren't a lot of things in it and it was clean and simple as I put in the questions. I also liked how we were able to skip the problem once we finished it instead of waiting until the timer was out It was formal and clean and I could do things a bit easier than a normal worksheet. Also, this includes videos to help with learning and was just simple and easy It reads you the problem and for me, it is always easier if someone reads me the problem I liked that it was the voice and not any annoying voice that is a robot and I can understand the voice clearly Buttons. When there are buttons I can press them. Like check mark bullet point buttons
Self-paced learning Subcode: · Pause · Independent	References to independence, do on your own time, pausing, breaks Self-pace: pause: mention of the ability to pause course Self-pace: independent: the ability to work by oneself *Inclusion: include if in reference to freedom to complete course on your own time* *Exclusion: don't include if simply describing accessibility through devices*	Something I liked about the online activity is that I could mostly go at my own pace Coming from a person who does not like to use technology to learn is that I liked that I could pause the video and I was able to type out my answer I enjoyed that I could pause it if I needed to stretch or take a break for a couple seconds. I also liked that I could work at my own pace I like that I can just click or type the answers instead of writing them down. I also can pause the lesson if I need a break

Table 6 (continued)

Analytic category: The LXD of the course revealed several key design facets to iteratively improve		
Codes	Definitions	Example
Not enough time · Extend · More · Time limit · Rush	References to the time limit set per problem on the course and students' feelings of being rushed Extend: references to students mentioning the possibility of extending time allotted per problem More: referenced to students highlighting how more time is required to complete each problem Time limit: students referencing how the time limit distracts their learning Rush: students mentioning how they felt rushed during the learning process *Inclusion: include any references that focus specifically on the time it takes to solve problems while in the coruse* *Exclusion: exclude if referencing time to complete the research study, normal class time, or time in school*	I think there shouldn't be a time limit. It makes students feel rushed and that they don't have enough time. It also makes the students not focus and worry instead Let people have time. To have as much time as they want. So they can answer the question without feeling worried I think having no timer will make it better because, well it does get me to work faster on solving math, but it also pressures me to rush Maybe for time to answer the question, because if students are rushed, they will probably panic and not think twice about the answer
Interactive gamification & design · Gamification · Design Requests · FAQ	References to improvements to the online course design, interactive elements, and lesson activities Gamification: references to students mentioning how the online activity could take incorporate games, challenges, and stories to guide the learner Design requests: references to pedagogical course design features, activities, visual improvements, and math implementation FAQ: mentions of a frequently asked question bank or bot that allows students to chat or review problems after they have solved it *Inclusion: include any references that focus specifically on the improvements to the online course, the pedagogy, design, and math content* *Exclusion: exclude if referencing math in their respective classroom, improvements unrelated to the math study, or comments about other online experiences unrelated to this experience*	If there was a dropdown at the end of the video asking if you had different common questions for parts you did not understand If the problem had a place maybe greenscreen a background so someone acts like they are their in that place maybe doing that thing like cooking The ability to fast forward and rewind. When the person explains, having her not explain in so much detail I believe you should add a part at the end and on the website where it reveals your scores to know how you are doing and what you need to work on I think that they could make fun games and make it more exciting, and if it was not online. This would make it more fun to me The online learning activity would be better if they had a server where people can ask questions about the lesson and someone would reply and answer them

Student F: "I liked how Mrs. Marland [teacher in the video] found different strategies to answer the same questions."

Theme 3: The user experience of the online course influenced students' learning experience.

User experience was defined as the ability for students to utilize the learning interface with ease to accomplish the learning task. More specifically, we leveraged technological affordances and created an interface that is simple, easy to navigate and click through, pacing, interactivity, and visually appealing.

Student G: "I liked how there weren't a lot of things in it and it was clean and simple as I put in the questions. I also liked how we were able to skip the problem once we finished it instead of waiting until the timer was out."
Student H: "It was formal and clean and I could do things a bit easier than a normal worksheet. Also, this includes videos to help with learning and was just simple and easy."
Student I: "Coming from a person who does not like to use technology to learn is that I liked that I could pause the video and I was able to type out my answer."

Theme 4: The LXD of the course revealed several key design facets to iteratively improve.

Capturing students' commentaries on how the blended course might be improved was essential to further develop and iterate our design. Improvements were defined as any suggestions, comments, or feedback that specifically highlighted how the blended course can be improved for other students. More specifically, these were direct references to insufficient time, suggestions for innovative interactive gamification, and enhancements to the course design that might better support their learning experience.

Student J: "I think there shouldn't be a time limit. It makes students feel rushed and that they don't have enough time. It also makes the students not focus and worry instead."
Student K: "If there was a dropdown at the end of the video asking if you had different common questions for parts you did not understand."
Student L: "I think that they could make fun games and make it more exciting, and if it was not online. This would make it more fun to me."

Discussion

In this study, a blended learning mathematics course was implemented for elementary students, combining the principles of Learning Experience Design and the Cognitive Apprenticeship Model pedagogical learning framework. The objective was to examine how the students' situational interests and user experience impacted their engagement in the course. This research was conducted during a critical shift back into the classroom after a period of predominantly online learning, presenting a unique opportunity to research evidence-based methods to leverage education technologies such as blended video-based learning to support teaching and learning in face-to-face environments. The quantitative analysis demonstrated that both SI and UX significantly predicted students' engagement. Furthermore, qualitative analysis of student evaluations reported that video lessons contextualized within real classroom scenarios were key motivators. Additionally, the use of diverse problem-solving strategies by teachers was found to enhance students' situational interest and overall engagement. These findings highlight the value of adopting a blended learning

approach that integrates the LXD paradigm and CAM, illustrating the benefits of combining learning theories, pedagogical implementation, and user experience design principles. This also illuminated how blended approaches can seamlessly bridge online and classroom instruction, creating a more adaptable and effective educational experience. Consequently, the study demonstrates the importance of merging pedagogical frameworks and UX design principles to optimize student engagement in blended learning contexts. The findings suggested that deploying a blended learning approach based on the LXD paradigm and the CAM instructional design framework enhanced students' SI. Moreover, attention to UX design elements such as ease of use, findability, and navigability contributed to students' positive learning experiences. Therefore, the simultaneous integration of pedagogical learning design and UX design played a crucial role in fostering students' engagement within the blended learning experience (Simunich et al., 2015). The discussion will delve into these findings, examine their implications for learning experience design, and propose directions for future research.

RQ1: situational interest and student engagement

The findings of this study demonstrated that SI significantly predicted student engagement in the blended learning mathematics course (See Tables 4 and 5). The deployment of the Learning Experience Design framework, operationalized through the Cognitive Apprenticeship Model pedagogical model, played a pivotal role in fostering students' SI. Specifically, the course was designed within the LXD pedagogical framework and placed emphasis on experiential learning through hands-on activities and "learning by doing" experiences (Floor, 2018; Weigal, 2015; Wong et al., 2024). CAM's instructional elements—including modeling, coaching, scaffolding, articulation, reflection, and exploration—anchored students' learning experiences in practical and interactive activities (Brown et al., 1989; Ghefaili, 2003; Wong et al., 2023). The CAM framework promotes the transfer of knowledge and skills to real-world contexts by providing learners with opportunities to practice in authentic settings (Collins, 1991; Collins et al., 2004). In order to enhance the ecological validity of the classroom environment, the learning videos were pre-recorded with the active participation of a teacher, 5th and 6th-grade students, math specialists, content experts, and instructional designers who were directly involved in the course development. The decision to film the videos within an authentic classroom setting aimed to evoke a sense of natural realism and mitigate learner disengagement, resulting from the absence of an instructor (Sorensen & Donovan, 2017).

By recreating the classroom setting using video to resemble real-world situations, learners develop the ability to apply their knowledge in meaningful ways (Collins et al., 1989). Students' open-ended responses highlighted the impact of this approach, with comments such as: "I liked how there were students in the video so it felt like you were really in the classroom with them," and "I liked that it [blended course] was like you were in a classroom while you do the video. I understood a lot which helped me a lot with the questions being asked" (see Table 6). These videos, designed to support students in navigating their learning systematically, created a realistic classroom atmosphere while fostering an engaging blended learning experience. Elements such as embedded questions, student discussions, presentations, and reflections intentionally encouraged active, student-centered learning. The immersive design of the videos, coupled with their ecological validity, aligned with Schraw et al.'s (2001) recommendations for promoting situational interest

(SI). As students reported, the realistic classroom context increased their curiosity, intrinsic motivation, and perceptions of the lessons' applicability. The scaffolded video experiences allowed students to follow along with the teacher and their peers, staying engaged and actively participating in their learning journey.

As a result of our design intentions, students felt like they were in a real classroom, watching real students and teachers, which may have increased their curiosity to learn, personal intrinsic motivations, and feelings about the lesson's applicability. By preserving the ecological validity of the classroom environment and adhering to Schraw et al.'s (2001) recommendations for promoting students' SIs, the results suggested that learners were able to follow along with the teacher and students immersively while staying engaged within the learning experience. In summary, this study demonstrated that situational interest played a crucial role in driving student engagement within the blended learning environment. By leveraging the LXD framework and CAM principles, the course design effectively combined pedagogical strategies and interactive tools to foster a realistic, engaging, and student-centered learning experience. These findings underscore the importance of designing educational experiences that balance ecological validity and active learning to optimize student outcomes.

RQ2: user experience design and engagement

The study revealed a significant correlation between students' user experience and their engagement within the blended course, highlighting the critical role of intentional UX design in blended learning environments (See Table 4). Regression analysis further demonstrated that students' user experience was a strong predictor of their course engagement (See Table 5). Several key course design facets may attune our understanding to explaining these trends. First, this blended course utilized a newly developed learning interface that was easy to use, making use of a consistent user interface design system, such as vectors and placement of buttons, as well as usability instructions that guided learners through each step. Adopting Nielsen's (2005) usability heuristics as a user interface standardization for our UXD efforts afforded greater navigability, usability, and simplicity for students using a new system for teaching and learning. We see these patterns emerge in the qualitative findings with students referencing "how there weren't a lot of things in it [course platform] and it was clean and simple as I put in the questions," the enhanced accessibility of the blended course was able to "read you the problems, it is always easier if someone reads me the problem," and how "it [blended course] was formal and clean and I could do things a bit easier than a normal worksheet, also, this course includes videos to help with learning and was just simple and easy" (See Table 6). As instructors and researchers, these data from students showcased how our user experience design components aligned with the intended effect of the learning interface. Aligning with past research on the intention of UX designs for educational course design (Wong et al., 2023, 2024) these results also help to explain how the design of an interface may sustain students' engagement within the course and help to alleviate tensions from having to troubleshoot the platform, redirecting students' attention towards learning the material.

Secondly, the benefits of blended instruction included learner independence, individualized instruction, personal flexibility to review and practice, and increased student agency and autonomy (Holmberg, 2003; Xu & Zhou, 2020). Analyzing the qualitative data revealed emerging patterns with students commenting how "coming from a person who

does not like to use technology to learn, I liked that I could pause the video and I was able to type out my answer," the accessibility of the course platform afforded the ability "to skip the problem once we finished it, instead of waiting until the timer was out," and how "I enjoyed that I could pause it if I needed to stretch or take a break for a couple of seconds, I also liked that I could work at my own pace" (See Table 6). These findings are consistent with the literature as they argue that when learners practice self-pacing (Tullis & Benjamin, 2011) and can actively engage in their own productive metacognitive judgments (Toppino et al., 2009), they are more likely to stay engaged in the learning environments. As such, the UXD might be affording students a way to monitor their own metacognitive judgments by exploring the course content (i.e. videos, interactivity, practice questions), identifying what they know and clarifying what they do not know at their own pace, and providing learners independent control over their own study-time allocation (Benjamin & Bird, 2006; Toppino et al., 2009).

RQ3: the integration of LXD and UXD supporting students' learning experience

The integration of Learning Experience Design (LXD) paradigm and User Experience Design (UXD) principles effectively supported students' learning by combining pedagogical depth with intuitive usability. The LXD framework operationalized through the CAM pedagogical model focused on scaffolding, real-world context, and student-centered strategies, while UXD principles ensured the course interface was simple, navigable, and engaging. Quantitative analysis underscored the importance of this approach, revealing significant positive correlations between situational interest (SI) and both perceived learning engagement (PLE) ($r = .613$, $p < .001$) and UX ($r = .634$, $p < .001$). A statistically significant connection was also found between UX and PLE ($r = .521$, $p < .001$), affirming that an intuitive, user-friendly interface enhances student engagement. Regression analysis showed that both SI ($\beta = .471$, $p < .001$) and UX ($\beta = .227$, $p < .001$) positively predicted PLE, together explaining 40.73% of its variance ($R^2 = .407$). These findings highlight the synergistic impact of combining LXD and UXD principles, emphasizing their crucial role in fostering a cohesive and engaging learning environment that promotes both interest and meaningful engagement among students.

This synergy between LXD and UXD also created an environment where students could explore mathematical concepts through multiple strategies, fostering deeper understanding and flexible problem-solving skills, ultimately highlighting the critical roles of both pedagogical strategies and user-centric design in shaping effective learning experiences (Floor, 2018; Weigel, 2015; Wong et al., 2024). From a pedagogical lens, students highlighted the impact of the teacher's use of multiple solution strategies as a pedagogical technique, noting how diverse examples and approaches helped clarify mathematical concepts (Begolli et al., 2014; Richland et al., 2017). For instance, Student D shared, "I really liked how they used many examples to explain one type of problem instead of only using one. The teacher let other students go up to the board and show how they did the work. I was able to understand it better." Similarly, Student E remarked, "I liked how…she went over the problem multiple times with different strategies," while Student F appreciated how the teacher "found different strategies to answer the same questions." These qualitative insights demonstrate how the course design encouraged flexibility and conceptual understanding by exposing students to alternative approaches. Importantly, the combination of LXD and

UXD decisions also allowed students to recognize their initial understandings of math concepts and provided ample time to reflect and practice immediately. This approach empowered students to take control of their learning pace—within the limits of classroom time—and adapt their behaviors to remain engaged. The simultaneous integration of pedagogical learning design and UX design thus emerged as a pivotal strategy for supporting students' situational interests and course engagement, particularly in blended courses leveraging the LXD paradigm.

From a user experience design lens, the course design elements further amplified this engagement by making the platform easy to use and supportive of autonomous learning. Students noted the clarity and accessibility of the course, with comments like Student A's: "I liked that the lessons were thorough and easy to follow along to. I also liked how there were students in the video, so it felt like you were really in the classroom with them." The humanizing and interactive design of the videos, coupled with the usability of the platform, created a learning experience that was both intuitive, empathetic, and immersive. By aligning the pedagogical strengths of LXD with the practicality of UXD, the course design facilitated an engaging and effective blended learning environment. This thoughtful integration not only supported cognitive engagement but also encouraged emotional connection and sustained curiosity, offering a model for designing impactful educational experiences through blended video learning approach for elementary mathematics.

Constraints and limitations

Certainly, more research is warranted to further evaluate the limitations to and affordances of blended learning experiences with elementary students. Based on the suggested improvements gleaned from the qualitative data, we uncovered several constraints in our design that hindered students' learning experience. These design constraints include insufficient time to finish problems, lack of immediate feedback, and inability to freely navigate the learning interface. As a research design decision, we chose to program a specific time limit per question due to the limited classroom research time allotted while conducting research. Typically, researchers are only allowed a certain time frame within their allotted math block to conduct classroom research. This greatly limited our capacity to ensure that all students were able to reach the end of the math lesson. As such, our solution was to add a timer for each math question to help guide students with their pacing throughout the blended math lesson. Additionally, given the one-hour time classroom constraint, we chose to not include immediate feedback of students' responses within the learning interface but rather showcase the solution key of worked examples after students have, submitted their answers. This design option was chosen to reduce friction and time dwelling on scores to ensure students were able to see the solutions worked out instead. However, future follow-up studies currently in development will explore the potential for Generative Artifical Intelligence (GenAI) to provide tailored feedback to students to further develop their higher-order thinking skills. Lastly, the inability for students to freely navigate the blended courses like an asynchronous course was a design decision to blend elements of synchronous learning while controlling experimental conditions such as treatment, time, random sample, and within classroom assignment.

While this specific study did not explore the treatment conditions between student groups, it was part of a larger multi-faceted research program that explores how relational reasoning and teaching with analogies improve math outcomes and higher-order thinking.

Given the experimental constraints combined with the classroom time allowed, we limited the navigability within the course to keep students moving forward in the course. Future experimentation will examine the effects of removing the timer and whether students' interests, user experience, and engagement might significantly increase. Importantly, this survey analysis was the first iteration of a multi-year analysis identifying the motivational and design factors influencing students' engagement through blended-learning experience. It is also important to take into account that the measured variables used in this study were self-reported. As such, we acknowledge the inherent constraints that are associated with the extent to which self-report measures are interpreted and have been taken into account. Furthermore, future follow-up analysis might also consider log analysis to obtain a more precise measure to capture students' course engagement data such as time on task, rate of course participation, rate of assignment submissions, and course grades. We also plan to conduct a quasi-experimental study that examines treatment differences between students' SI, UX, and engagement in a fully online mathematics course compared to a blended learning course with the same instructor, videos, and math course content, although differing in course modality. By adopting a multi-modal approach that integrates self-report measures, open-ended questions, and clickstream learning analytics data, a comprehensive and robust assessment of students' course behaviors can be achieved (Ellis et al., 2017). Collectively, this combination of methods allows for a more holistic and in-depth understanding of students' engagement and interactions within the course.

Conclusion

This study underscores the importance of integrating LXD and UX design to enhance situational interest and user engagement in blended learning environments. Blended learning approaches have been around for some time, but with the shift back to in-person classroom learning, there are renewed interests in integrating technology-mediated learning approaches that align with evidence-based theory and practice. This has important theoretical and practical implications for children's motivational and behavioral factors that can be immediately applied to blended teaching and learning. The LXD paradigm provides a framework for sustainably integrating technology into the learning experience, which can improve student engagement, motivation, and learning outcomes. This presents a unique opportunity to further research and identify how instructors might better support students' learning experiences as the remote learning context has paved the way for alternative learning modalities with education technologies. Based on our study findings, we have learned that students' engagement is, in part, explained by their user experience with the learning platform and situational interests within the course. Gleaning student commentaries revealed specific pedagogical and user experience design features that further enhanced students' learning experience within the blended learning course. Pedagogical design features such as the teacher's physical presence in the video, segmented multi-camera video angles (i.e. teacher view, student view, document desk view, whiteboard view), and simultaneous multiple visual representations of solution strategies. Regarding the user experience design, students mentioned how the interface was easy to use, included accessible usability instructions, and utilized consistent elements of design to guide the learner through the course. While the results in this study are correlational, we suspect that the underlying mechanism linking LX design and engagement is likely to be the resulting effect of increasing students'

SI and UX. These results are important as it affords instructors to consider the LXD paradigm to better attend to factors that positively impact students' mind-wandering and online engagement. Thus, our study makes an important contribution to testing the efficacy of LXD with educational technologies as it suggests design factors that contribute to students' user experience, situational interest, and students' online engagement. Moreover, these results add to our understanding of students' learning experience during the transition back from emergency remote distance learning, which will serve as the foundation for future experimental research iterations to implement learning design principles based upon theories that aim to increase student engagement. In conclusion, this study supports the literature on student engagement and improving blended learning experiences through LXD, informing LX designers and practitioners on how we might effectively co-design and iteratively improve teaching and learning for future instances of traditional, online, and blended modalities of instruction.

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Data availability The data that support the findings of this study are available from the corresponding author, Joseph Wong, upon reasonable request.

Declarations

Conflict of interest There are no conflicts of interest to report. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Informed consent Informed consent was obtained from all participants in the study and all procedures were approved by the Ethics Committee of the University of California, Irvine.

Research involving human and/or animals participants Approval to conduct research involving human participants were obtained and approved by the Institutional Review Board at University of California, Irvine.

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