Utilizing Learning-Analytics-Based Activities as a Bridge to Enhance Elementary Students' Mathematical Learning

Sergio Tirado-Olivares, Rocío Mínguez-Pardo, Javier del Olmo-Muñoz, and José A. González-Calero

***Abstract*—Decimal misconceptions are a persistent challenge in mathematics education, often hindering students' long-term understanding. This study examines how learning analytics (LA) can be effectively integrated into instructional sequences to address these misconceptions, providing teachers with real-time insights for formative assessment. Despite the growing presence of technology in education, LA remains underutilized at the primary level. The study involved 235 fifth- and sixth-grade students completing decimal number tasks through a Moodle-based platform. Students were assigned to one of three conditions: tasks based on correct examples (CE tasks, $n = 79$), erroneous examples ($n = 80$), or no tasks (control group, $n = 76$). Results indicate that example-based tasks significantly improve learning outcomes, particularly for students with lower prior knowledge, who benefited more from CE tasks. LA data effectively predicted student performance, demonstrating its potential as a formative assessment tool. Importantly, results suggest that the observed effects were consistent across male and female students. These findings highlight the need to integrate LA into daily teaching practice, enabling educators to identify misconceptions and tailor instruction accordingly. Given the positive student reception and the efficiency of LA-driven interventions, this study underscores its relevance for policy decisions aimed at enhancing mathematics education in primary schools.**

***Index Terms*—Decimal numbers, example-based learning, formative assessment, learning analytics (LA), primary education.**

Received 30 December 2023; revised 6 February 2025, 29 March 2025, and 12 May 2025; accepted 14 May 2025. Date of publication 16 May 2025; date of current version 6 June 2025. This work was supported in part by project PID2023-150960NB-I00, funded by the Spanish Ministry of Science, Innovation and Universities and the European Union; by project 2022-GRIN-34039, funded by the University of Castilla-La Mancha and the European Regional Development Funds; by Grant/Award Number 2023-PRED-21319, funded by the University of Castilla-La Mancha. *(Corresponding author: Javier del Olmo-Muñoz.)*

This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the ethics committee of the University of Castilla-La Mancha (Date 07.04.2022./No. CEIS-632710-Z1N4), and performed in line with the Declaration of Helsinki).

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Digital Object Identifier 10.1109/TLT.2025.3570979

I. Introduction

TODAY's education demands tools to expand and improve the monitoring and feedback processes of monitoring and providing feedback concerning the teaching-learning process. In this search, Stanja et al. [1] proposed that the use of learning analytics (LA hereinafter) in the field of education is currently gaining a lot of interest because of its potential. In fact, as the EDUCAUSE Horizon report stated, LA will be one of the most important technological trends in the short–medium term [2]. Interest in it is justified because LA allows the collection and analysis of large amounts of information almost immediately, not only about the student's own learning, but also about everything involved in the learning process [3]. However, as Dubé and Wen [4] and Rodríguez-Martínez et al. [5] pointed out, concrete evidence is needed regarding how to implement it effectively in the classroom.

Amarasinghe et al. [6] emphasized that the use of LA in the teaching–learning process offers information that can be of great interest in the design and development of tasks, although little research exists that focuses on this issue. Hence, more research about developing and analyzing the potential of LA tools and design models about how to use them effectively is necessary [7]. The need for more studies is vital at elementary education levels, as there is little evidence concerning the use of LA at this educational stage [8], [9]. Integrating LA with elementary students does not require unfamiliar resources for teachers [5] as this study aims to demonstrate. Using digital platforms gives teachers tools to monitor learning and allows students to learn at their own pace. [10].

Moreover, this design of learning sequences monitored using LA is especially relevant in areas such as mathematics, since its use can allow the analysis of possible comprehension problems for students at an earlier age. In fact, the detection of misconceptions enables a personalized educational approach, as this information tells us the content the student needs to work on more, what tasks they need to do to improve understanding, or if there are prior assimilation misconceptions [5]. The need for early detection of these misconceptions is especially relevant when students are learning decimal numbers as this is one of the contents which students often find difficult [11]. Furthermore, given the differences in academic mathematics achievement in favor of boys [12], [13], LA may be a powerful tool to monitor the learning process and detect gender gaps at an early stage.

However, there are limitations in the current literature concerning the use of LA in the assessment of students' conceptions [1]. In this regard, the ability to analyze if students can identify their errors enables teachers to understand the misconceptions students may have already assimilated. LA can help teachers to prepare tasks and assess these misconceptions whenever they arise.

In this setting, we explore the pedagogical approach of example-based (EB) learning, an instructional strategy that emphasizes the use of correct examples (CE) and erroneous examples (EE) to enhance the learning process. The benefits of studying CE have been widely documented in educational research, showing significant improvements in learners' ability to solve problems efficiently and effectively [14]. There is also evidence in the literature which endorses the potential of working with EE [11], [15], although it seems to be mediated by students' prior knowledge [16], [17]. To the best of our knowledge, instructional approaches that combine the potential of LA and EE have not yet been evaluated.

Considering all these aspects, this research seeks to investigate the potential of LA in primary mathematics education and the advantages it offers by leveraging the vast amount of data collected on the teaching and learning process. This study hopes to contribute to the educational community in three key areas: 1) to design digital tasks that can improve not only the academic achievement of students but also their formative assessment; 2) to use the LA information to identify students' difficulties in their daily academic performance; and 3) to understand students' perceptions about completing these digital tasks at home, in terms of interest and usefulness, in order to analyze their willingness to complete them as daily classroom assignments.

II. Literature Review

A. LA and Task Development: Enhancing Individualized Learning Environments

Designing personalized teaching and assessment methods is essential in today's education [2]. Although personalized methods make it possible to provide more effective, individualized, and continuous feedback [5] this process is still commonly developed under classical summative paradigms. This is partly because collecting data manually on each student's progress takes considerable time and effort [18]. In fact, manual data collection is one of the main drawbacks when considering alternative evaluation plans for teachers, due to the number of students and associated tasks that must be evaluated. Hence, teachers tend not to implement continuous evaluation plans and personalized feedback in practice [19]. Therefore, the integration of technologies could be a feasible solution.

Nowadays, the use of technology in the teaching–learning process is increasingly in demand. These technologies provide the educational community with tools and new pedagogical approaches that enable a change in the learning perspective. In fact, competency frameworks, such as the European Digital Competence of Educators, emphasize the need to encourage autonomous student work in teaching sequences adapted to their individual needs [20]. As indicated in this framework, the use of LA enables this increase in continuous knowledge about the teaching-learning process, and the application of quicker and more effective measures adapted to each student. Many definitions of LA exist, but one of the most widely used is proposed by Long et al. [3]: "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (p. 1).

As highlighted in the 2022 Horizon Report [21], the great potential that LA can have in the foreseeable future is due to current technological advances, as this allows the collection of large volumes of information at any time and in broad educational contexts. In other words, educators can use LA information to monitor the effectiveness of teaching-learning processes [2]. However, as different authors pointed out, it is time to put LA into practice in the real education context and verify its potential with practical evidence [4], [6].

There are limited studies evaluating the impact of LA on the teaching-learning process, particularly in elementary education. This has been substantiated by recent systematic meta-reviews [8] and reviews [9], [22]. Gašević et al. [7] have identified three central lines of research on the relationships between LA and assessment that can set the roadmap for investigations in this area. The first is "analytics for assessment," understood as the use of LA approaches to support the assessment of learning. The second research line "assessment analytics" refers to the development of approaches to analyze the principles of existing assessment practices. The third "measurement validity" refers to the development of conceptual models and practical approaches to ensure measurement validity through LA.

In this article, we focus on two of these lines of study. In particular, by integrating LA in the teaching of decimal numbers in primary education (the first line), we aim to offer a valuable formative assessment tool for teachers from a didactic perspective. This approach takes into account documented common misconceptions in the understanding of decimal numbers. It is designed to equip teachers with data-driven information, enabling them to adapt their teaching strategies effectively and make well-informed decisions to address students' needs. At the same time, we aim to measure its validity (the third line) by assessing how the LA data gathered throughout the project are aligned with the test-type assessment (written test) performed by the students at the end of the project. Regarding gender, it is particularly important to be able to detect differences in students' academic achievement in mathematics, as well as their causes, in order to take early action.

B. LA and Mathematical Competence Under a Gender Perspective: Integration of EB Tasks in the Teaching of Decimal Numbers

Although there are many studies which focus on the application of LA in mathematics, there is still a lack of studies on its use in primary education [5]. Recent systematic reviews highlight that existing research in K-12 is insufficient to address the complexity of its implementation. These reviews indicate the benefits of the application of LA across various curricular contents within the mathematics classroom, demonstrating its positive impact on most students. However, there is a need to develop deeper knowledge about its use and practice within the mathematics classroom [23]. This is essential, as LA can help teachers predict student achievement and identify students at risk of dropping out [24]. When applied to decimal numbers, LA allows quick detection of misconceptions, making it possible to respond promptly with actions tailored to each student's needs [2]. Students' misconceptions related to decimal number learning are systematic and common; hence, they are predictable [25], [26], [27], [28], [29]. Considering that misconceptions are an inherent part of learning decimal numbers which persist over a long period of time [30] and can internalize ideas which are difficult to change [31], LA could become particularly significant when dealing with decimals.

Although different methods for diagnosing misconceptions have been reported in the literature, LA provides teachers with a new tool, which overcomes some disadvantages of previous approaches, such as time consumed by interviews [26], [32] or limited answers from multiple-choice tasks [33]. Hence, when addressing the type of tasks students should perform regarding decimal misconceptions, unfamiliar models (e.g., a number line) could offer them the opportunity to reflect and achieve a better understanding [34]. In this context, LA provides an opportunity to manage and analyze information about student performance and to give personalized feedback or even personalized learning sequences. Obtaining this information in real time is a major strength because of the influence that the teaching methodology can have on student performance, especially when learning decimal numbers using an EB approach. In this regard, research affirms that using CE is useful for learners, both those with low prior knowledge and those with high prior knowledge [14]. However, the effectiveness of EE seems to be mediated by the learners' prior level: EE is more effective for high prior level students than for low prior level students [17]. As suggested in [16], it is important to have a basic grasp of the instructional material in order to be able to process the information at a deeper level and, thus, benefit from EE. This distinction aligns with constructivist perspectives, which assume that learning occurs through the active construction of knowledge based on existing cognitive structures. From this viewpoint, CE tasks offer clearer support to learners with limited prior knowledge, while EE tasks require more developed internal frameworks to be processed effectively.

Concerning the differing performances of males and females in mathematics, international assessments, such as the Program for International Student Assessment (PISA) or Trends in International Mathematics and Science Study (TIMSS), provide us with a general image of the gender gap. According to TIMSS 2019, there are significant differences between boys' and girls' performance averages in close to half of the 58 participating countries; particularly in Spain, achievement differences in mathematics are higher than the average [13]. Nevertheless, considering PISA 2018 results, the differences in mathematics achievement have been reduced in compared to previous years, even though males still outperformed females [12]. In this context, LA can help address a key limitation in previous research on gender gaps in mathematics education: the reliance on overall scores without analyzing specific skills or item-level differences [35]. Related to this, a recent analysis based on a model tries to quantify gender differences when addressing specific mathematical items [36]. When comparing number tasks, differences between males' and females' performances were found. These tasks were more challenging for girls, especially when they involved comparing decimals. Likewise, considering estimating tasks, the gender gap persists; girls present specific difficulties when solving these kinds of tasks, leading to worse results in the overall test.

C. How to Implement LA in Primary School? Digital Platforms

Every learning activity must be designed taking into account the intended learning objectives [37]. The use of digital platforms to perform academic tasks allows the adaption of learning sequences to the students' own capabilities [38]. As pointed out in [39], their use is not only gaining popularity but also presenting positive results when used with primary school children. Digital platforms allow the integration of theoretical contents and activities in an interactive way providing a user-friendly interface for students. One of the most commonly used digital platforms that meet these characteristics intuitively is Moodle [40]. According to Ros Martínez de Lahidalga [40], its use enables autonomous learning spaces in which both the students and teachers can regulate how this learning is taking place. When using digital platforms, such as Moodle, contents can constantly be updated, with large amounts of accessible information about the results, as well as the learning process [41], facilitating the integration of LA in the classroom.

Teachers need to know whether the tasks are useful for students, so they can design them in line with educational goals and learners' needs. By using LA in digital platforms, teachers can easily obtain relevant information about how their students are studying and learning. Usually, this task is quite laborious without technological assistance, but platforms like Moodle automatically collect relevant data, such as the time spent on the course, the number of activities done, or assessment scores [1], [10]. However, its potential is not only based on the increased information gathering and the possibility of using this information to predict students' academic performance on subsequent tests [1], [42], [43].

The systematic review conducted by Magalhães et al. [44] stated that online homework is more effective in promoting students' performance compared with traditional homework. The completion of tasks on digital platforms eliminates spatial time barriers and enables students to adapt learning to their own pace, which may lead to a better outcome [38]. However, Magalhães et al. [44] highlight the existence of methodological limitations in existing studies on homework. For instance, some studies failed to control key variables when comparing both formats of homework (e.g., students in the online condition completed tasks individually, whereas those in the traditional condition worked in groups)—an imbalance that introduces a confounding variable and may compromise the validity of the comparison. Therefore, future research should adopt more robust designs, such as randomized sampling and the use of standardized assessment tools, to ensure more accurate and reliable conclusions about the effectiveness of online versus traditional homework.

On the contrary, as pointed out in [44], most of the platforms used in compulsory levels are produced by textbook publishers. Hence, teachers do not have the opportunity to personalize and modify activities or even create tasks, therefore not providing pupils with activities adapted to specific didactic objectives and their needs [37]. Working with personalized digital platforms addresses not only the diagnosis of different misconceptions when considering decimal numbers—because of students' exposure to different activities [45]—but also the opportunity to work toward a better understanding with unfamiliar models [34]. When confronting unusual models in learning decimals, the number line is less common [11] and poses a greater challenge for pupils in primary education [46], [47]. Thus, it could be useful to incorporate complementary interactive models that allow students to work with a number line, such as GeoGebra, which has been shown to enhance students' reasoning and visualization skills [46] and can also be integrated into Moodle through its dedicated plugin. Therefore, it is interesting to analyze platforms such as Moodle in primary education to focus on proven effective tools to address the usual difficulties that students face when learning decimal numbers. Promising results have already been obtained in primary math lessons in terms of academic performance [39], though there is still a long way to go.

Through this research, we can help fill the gaps in the literature surrounding LA in compulsory education. Most importantly, the outcomes can enrich existing studies on the integration and impact (if any) of LA in the classroom. The present study also covers the evaluation of LA use in enabling the formative assessment of elementary math students and their feedback on the project. These ideas shape the proposed research questions (RQs).

D. Research Questions

Considering the potential that LA could have in the design and completion of mathematical tasks, the following RQs drive the development of this study.

1) *RQ.01:* Do the students' prior levels of proficiency, completion of CE or EE tasks, and gender influence the level of understanding of decimals?
2) *RQ.02:* Taking into account the partial effects of gender, experimental condition, number of tasks, and scores obtained, can LA predict the level of students' decimal number knowledge?
3) *RQ.03:* What interest and usefulness do students perceive after completing the designed tasks with the digital platform?

III. Method

A. Design

To answer these RQs, a quantitative and experimental study with pure randomization was carried out. This design was able to be developed due to the nature of the tasks posed in which the students worked autonomously within Moodle. This design reduces the influence of unrelated variables and makes it easier to replicate the study [48]. This design is supported by different researchers [49] who described it as the most rigorous way to study causal relationships between the study variables, since all previous existing differences are left to chance.

Therefore, since both experimental conditions included students from each class, possible biases such as differences in the students' previous level of mathematical competence linked to decimal numbers, or due to the role of the teacher, were avoided.

B. Participants

In order to contact the schools participating in the study, the required permissions were obtained from both the education administration of the autonomous community of Castilla-La Mancha and the ethics committee of the University of Castilla-La Mancha (Date 7 April 2022./No. CEIS-632710-Z1N4). Following this, the administration itself informed the schools via e-mail about this study. Interested schools were contacted and informed about the study's goals, procedure, and timeline.

Three schools from Castilla-La Mancha confirmed their participation. The initial sample consisted of 380 students in the fifth and sixth grades of primary school. However, for the analysis of preestablished objectives, only those participants who took the pretest and posttest, gave their consent to participate in the study, and identified their gender were selected. The sample was finally made up of 235 students (124 boys and 111 girls).

To comply with the experimental design, these 235 students were randomly assigned to one of the following experimental conditions. The randomization was facilitated through the use of the Moodle platform, as each student was assigned a username and password that randomly corresponded to one of the experimental conditions (CE or EE), sequentially distributing names from the participant list. The first condition, made up of 79 students (39 boys and 40 girls), focused on different tasks based on CE previously shown to students. In the second experimental condition, made up of 80 students (40 boys and 39 girls), the same tasks were performed, but, in this case, EEs were previously presented to students. To be considered in these experimental conditions, the students had to have completed at least three of the four tasks included in the project. The remaining 76 students (45 boys and 31 girls) were considered in the third experimental condition established: No task group.

C. Instruments

For the execution and analysis of this research, four instruments were used for different purposes.

1) Students' Mathematical Learning: The Decimal Number Test: Before and after the assignments, students completed a pretest and a posttest to check whether there are differences in their decimal number proficiency linked to the tasks before and after the study. Specifically, this instrument was based on the test developed and validated by Durkin [11]. From this test, in order to reach the research objectives of this article, 50 items related to decimal concepts were used for the analysis. Those items not directly linked to the academic achievement reached in this mathematical content were discarded. In turn, the activities proposed in these items were grouped into four different dimensions.

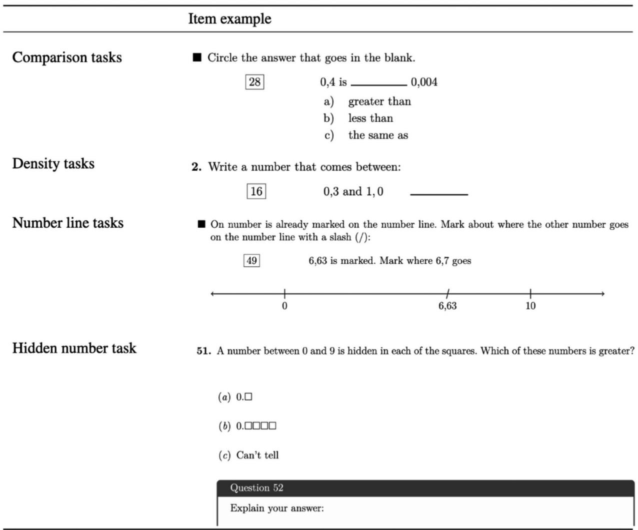

Fig. 1. Example of a text question for each dimension.

1) *Dimension 1—comparison tasks:* This dimension aimed at determining students' understanding of the real value of each number presented. This dimension includes a total of 25 items.
2) *Dimension 2—density tasks:* The purpose of this dimension was to assess students' ability to recognize the existence of infinite decimal numbers between two given values [26], [27], [29]. This dimension is evaluated based on five items.
3) *Dimension 3—number line tasks:* The activities linked to this dimension are designed to measure the students' ability to represent and identify values on the number line, and to establish relationships between given quantities [29]. This dimension is made up of 19 items in the test.
4) *Dimension 4—hidden number task:* This dimension allows for a general assessment of the students' concept of magnitude and their strategy for its interpretation [26], [27].

Finally, an additional question was included so that the students could state their gender if they wanted to. Fig. 1 shows an example of test questions for each of the dimensions described earlier.

2) Students' Perception of the Learning Sequence: Learning Object Evaluation Scale for Students (LOES-S) and Reduced Instructional Materials Motivation Survey (RIMMS): To check the students' opinions about how to perform decimal number EB tasks with the digital platform (RQ.03), two validated questionnaires were used.

First, the LOES-S developed in [50] was used. The five-level Likert scale items of this questionnaire were adapted to our learning object (the digital platform used) to evaluate the three dimensions of LOES-S: 1) learning; 2) quality; and 3) engagement of the learning object. Similarly, the RIMMS [51] was used due to its validity and the capability of this instrument to be adapted to experimental studies involving adaptative technologies. Previous motivational studies offered solid evidence of the usefulness of this test [52], [53]. This questionnaire has 12 items which the respondent must answer on a five-level Likert scale: from "totally disagree" (1) to "totally agree" (5). A total of 12 items of this questionnaire are grouped into four different dimensions: 1) attention; 2) relevance; 3) confidence; and 4) satisfaction [51]. This made it possible to detect which components were most affected by the performance of the tasks.

D. Procedure

1) Planning: The intervention phase of the study consisted of four weeks of tasks and the completion of the final assessment. The decimal number test was administered before the intervention period. Students were given 35 min to complete the test in order to measure their prior knowledge regarding the topic. In the classroom, where the test was performed, the students were forbidden to use any material other than a pen or pencil. These same conditions were repeated during the posttest at the end of the intervention.

In relation to the development of the tasks linked to the work on decimal numbers, these were to be done sequentially, once per week. These tasks were designed so that students could perform them autonomously at home via a digital platform (see Section III-D2) developed for this purpose. To familiarize students with the platform and address any questions, the first lesson was carried out at school. The configuration of each of the lessons is described in more detail as follows.

1) *Introductory lesson:* This was about 55 min long and included the pretest (35 min) and the first virtual lesson (20 min). The virtual lesson consisted of four comparison tasks, as described earlier, and three videos to explain decimal number concepts by using visual models such as base ten blocks and the number line.
2) *First work assignment:* All the other tasks were done at home and took about 15 min. This lesson was related to density. It was made up of four density tasks and two videos, one of them explaining the concept of density by using the number line, and the other one showing a student solving a density task in either the correct or incorrect way, depending on the condition.
3) *Second work assignment:* This lesson and the following one were related to the number line. In the second one, the students were provided with 15 tasks—12 of them designed with GeoGebra—and two videos. One of the videos was about identifying and representing numbers in the number line, and the other was an example of a student solving a task involving representing numbers in the number line, the correct way for one condition and the incorrect way for the other.
4) *Third work assignment:* This was made up of nine tasks—six of them designed with GeoGebra—and two videos which were different for each condition. In each video, a student solved a task in the correct or incorrect way depending on the conditions.

The first session, lasting about 55 min, was devoted to the pretest and the four comparison tasks described earlier. The second, third, and fourth sessions were developed at home, and each student completed the activities individually: the density tasks, number line tasks I, and number line tasks II, respectively.

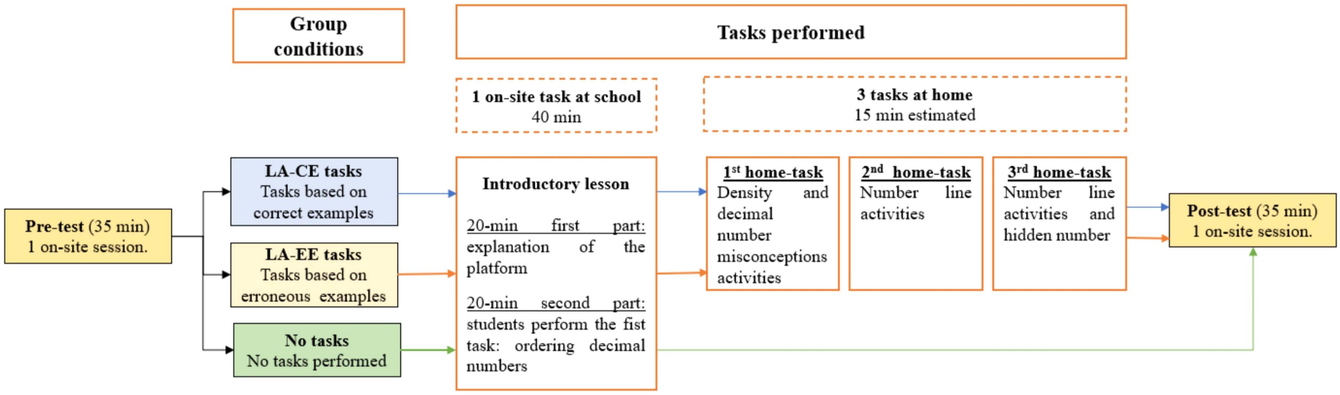

Fig. 2. Pedagogical dynamic implemented during the intervention.

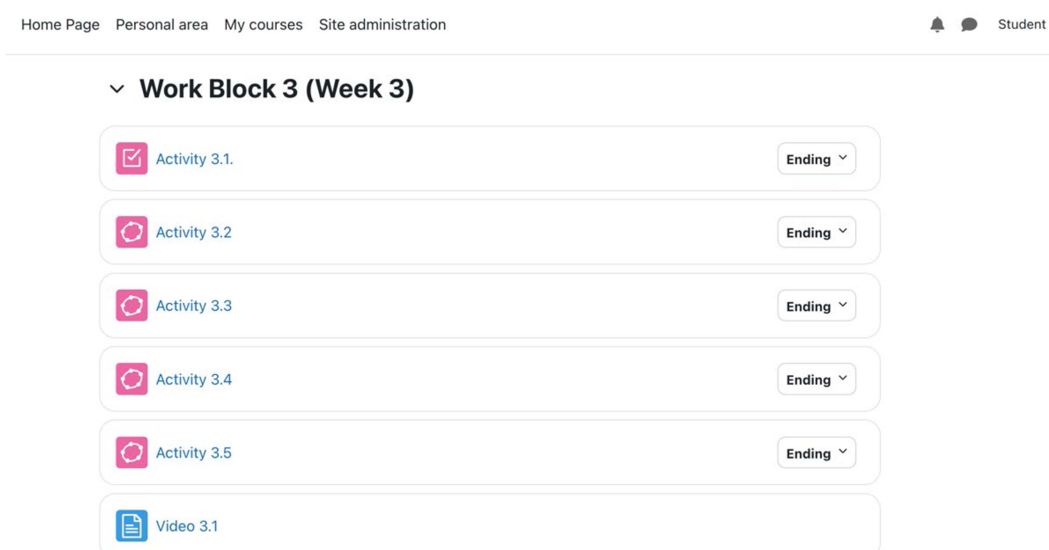

Fig. 3. Screenshot of the Moodle environment used.

Each task was designed to be completed in about 15 min. Finally, the students completed the posttest at school (see Fig. 2).

2) Digital Platform: In order to design and carry out the EB tasks, the digital platform Moodle was used. Within this virtual environment, an online course was designed to learn decimal numbers, and all the students were enrolled on this course. Fig. 3 shows a screenshot of the environment in which the students worked. Each student was given a personal username and a password that allowed him/her to access the activities in a controlled way. The proposed tasks were the same for all the students (see Fig. 4 for an example); however, some videos linked to the previously described work blocks were restricted according to the experimental conditions the students belonged to.

A total of 14 tasks were presented to the students over a period of four weeks. The structure of these tasks remained constant throughout this time. Each week, the students were assigned different tasks related to one of the dimensions previously described.

1) In the first week, four comparison tasks were proposed: two were devoted to order five numbers from least to greatest, one focused on the comparison between two numbers, and one related to recognizing decimal numbers represented on base ten blocks.
2) In the second week, the students completed four density tasks: two oriented to finding a number between two dice, and two related with approximation.
3) Finally, the third and fourth weeks were devoted to addressing the number line: three tasks each week concerning the identification of decimal numbers on the number line. The number line tasks were complemented by activities designed on the GeoGebra applet.

Apart from the GeoGebra activities, the rest of the digital tasks were based on the tools provided by the platform itself, including multiple-choice activities, correct answer selection activities, and fill-in-the-blank activities. Regarding the videos, the difference between the conditions was related to their content: in the case of the CE condition, the videos showed a CE of how to solve a task with decimal numbers (example of CE-condition video). For the EE condition, the videos showed a student, at the same educational level, solving the same task, but incorrectly (example of EE-condition video). These videos were followed

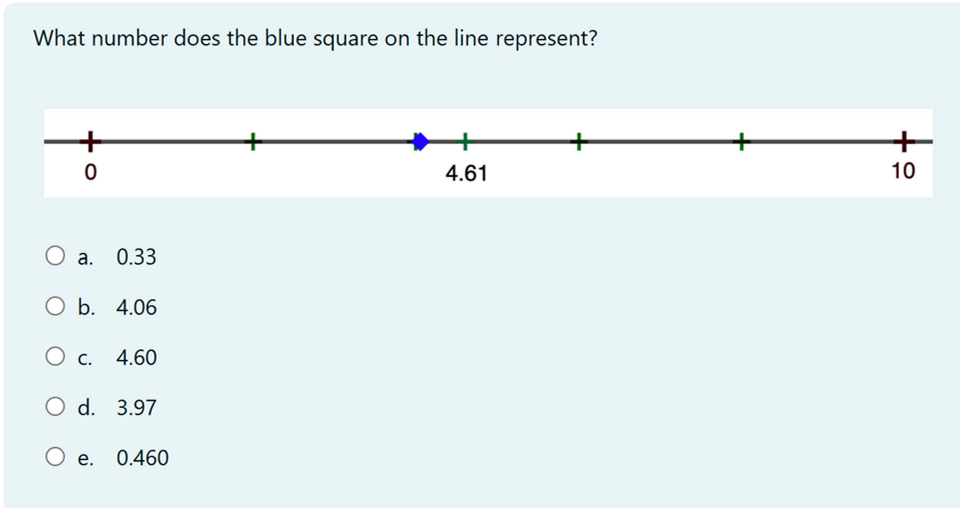

Fig. 4. Sample screenshot of a task as presented to students during the intervention.

by an explanation of the error made by the example student to make the students aware of it.

At the end of each task, the students could see which activities they had done correctly and which they had not done correctly; they were also able to see the correct answer and their score. In the case of GeoGebra tasks, the information provided to the students was not only their final scores but also a review of each individual error on the number line. In addition, GeoGebra was integrated within the Moodle platform, and while it did not store independent data, it returned a binary score to Moodle, indicating whether each task had been successfully completed or not. In turn, the Moodle platform generated a report on the number of activities performed each day by all the students enrolled on the course, the scores and time spent practicing at home. These reports allowed us to track participation and analyze learning patterns across the different instructional conditions.

IV. Data Analysis

First, to analyze the effects of tasks and their type (EE and CE tasks), a double moderation analysis was carried out. Posttest scores were used as the dependent variable, the experimental conditions as the independent variable, and the pretest scores and gender as the moderator variables. This analysis makes it possible to determine if the effect of EB tasks (if any) is moderated by students' prior understanding of decimals numbers and by their gender.

Concerning the coding, in both the pretest and the posttest, each item was marked binarily (1 and 0 for correct and wrong answers, respectively). For each participant, the prior proficiency level was calculated as the average (on a ten-point scale) of all the individual scores of items from the decimal test. The same procedure was used to calculate the final proficiency level using the posttest scores. With regard to the analysis of these scores, a planned contrast coding was applied to evaluate each of the direct effects. To test the effect of the tasks (RQ.01), we contrasted the No task condition against the EB task conditions (EE and CE tasks) by employing the following contrast weights: No task ($-2/3$), EE tasks ($1/3$), and CE tasks ($1/3$). To test differences in the effect of the two types of homework [RQ.01(b)], the following contrast weights were employed: No task (0), EE tasks ($-1/2$), and CE tasks ($1/2$).

For the moderating effects, moderated analyses were conducted with the macro PROCESS in R [54], and a Helmert coding based on [55] was used to analyze the interactions for each contrast. Again, the contrast weights were the same as the previous ones with regard to [RQ.01(a)]: No task ($-2/3$), EE tasks ($1/3$), and CE tasks ($1/3$). Type EB task contrast [RQ.01(b)] also maintained the target weights: No task (0), EE tasks ($-1/2$), and CE tasks ($1/2$). Finally, in case of significant interaction detected, the Johnson–Neyman technique [54] was applied to identify the regions of the pretest scores (moderator) for which the effect of the experimental condition on students' final level of proficiency was significant. This technique allows you to determine the specific values of the moderator variable at which the independent variable significantly influences the dependent variable, rather than relying on arbitrary cutoffs.

Regarding the second RQ, a multiple linear regression was used to verify the predicted potential of the EB task scores obtained using the digital platform activities. Multiple regression is a statistical method that assesses the relationship between one dependent variable and multiple independent variables, enabling the identification of the unique contribution of each predictor while controlling the others. The resulting effect size of the individual predictors was determined by calculating Cohen's f^2 with the semipartial correlation coefficients of the predictors as determined using R. Finally, to discover the level of student satisfaction and perceived usefulness linked to the EB tasks performed, nonparametric Mann–Whitney U-tests were used to analyze eventual differences based on gender, and Wilcoxon tests to contrast by dimensions. All analyses were carried out using the statistical software R [56] and with a significance level of .05.

TABLE I
DESCRIPTIVE DATA OBTAINED BOTH IN PRETEST AND POSTTEST IN EACH EXPERIMENTAL CONDITION BY GENDER

Condition	Gender	*n*	M_{pre}	SD_{pre}	M_{post}	SD_{post}
CE tasks	Boys	39	7.87	2.06	8.91	1.33
	Girls	40	6.61	2.10	7.87	1.92
EE tasks	Boys	40	8.16	1.44	8.89	1.09
	Girls	40	6.85	2.26	7.87	2.18
No task	Boys	45	5.65	2.67	6.21	2.68
	Girls	31	6.05	2.08	6.26	2.25

V. RESULTS

The results obtained have been sequenced according to the objectives previously described. For the first objectives, the sample was divided among the subgroups outlined in the participants section for the analysis of the predictive model of LA. Only those students considered to have done the activities (EB groups) were taken into account (RQ.02). Finally, to discover the students' opinions about these types of tasks (RQ.03), only those who voluntarily responded to the survey were analyzed.

A. RQ01. Academic Performance Achieved

First, regarding the pretest and posttest results by gender, the descriptive statistical data according to the three experimental conditions are shown in Table I. All groups improved in their decimal number proficiency. However, those students who did not complete the tasks reached a low level compared with those who did. The descriptive data show a higher level of mastery of decimals by boys compared to girls. To verify whether these differences were statistically significant, an inferential analysis of the data was performed.

A double moderation analysis with two moderators was conducted to evaluate if the effect of EB tasks on students' decimal number proficiency was influenced by the experimental condition (first moderator) and gender (second moderator). The analysis determined that there is no interaction between moderators and the independent variables ($F(2, 223) = 1.68$, $p = 0.1881$) nor between moderators [$b = -0.05$, $t = -0.15$, $p = 0.08848$ (Contrast 1); $b = -0.15$, $t = -0.35$, $p = 0.7288$ (Contrast 2)]. As a consequence, simple moderator analyses were conducted.

First, the analysis showed that gender did not significantly moderate the effect of EB tasks ($F(2229) = 1.83$, $p = 0.1620$). Nevertheless, it revealed that pretest scores were a significant moderator for the effect of EB tasks ($F(2229) = 9.94$, $p < 0.0001$). Indeed, the interaction was statistically significant for both Contrast 1($b = -0.21$, 95% *CI* [–0.32, –0.10], $t = -3.78$, $p = 0.0002$) and Contrast 2 ($b = 0.15$, 95% *CI* [0.02, 0.29], $t = 2.19$, $p = 0.0295$), indicating that the students' prior level of proficiency was a significant moderator of the impact on the effectiveness of EB tasks. The analysis also showed significant differences between the EB and No task groups ($b = 2.22$, $se = 0.38$, 95% *CI* [1.47, 2.98], $t = 5.83$, $p < 0.0001$), indicating a positive effect of EB tasks compared to No tasks (see Fig. 5).

A Johnson–Neyman analysis indicated that the effect of EB tasks compared to No tasks was statistically significant for students with pretests scores under 8.82; this implies that the tasks are effective for almost all the participants. In order to examine, in depth, to what extent the effectiveness of EB tasks was moderated by the students' prior level of proficiency, a second planned contrast was conducted comparing the two EB experimental conditions. In this case, a significant effect was found ($b = -1.34$, $se = 0.54$, 95% *CI* [–2.40, –0.28], $t = -2.49$, $p = 0.0136$). This result indicates that the students' pretest scores significantly moderate the impact of the activities mediated by LA for the two EB experimental conditions. The Johnson–Neyman technique demonstrated that the statistical differences between CE and EE task conditions took place for students' pretest scores under 6.75 (see Fig. 6).

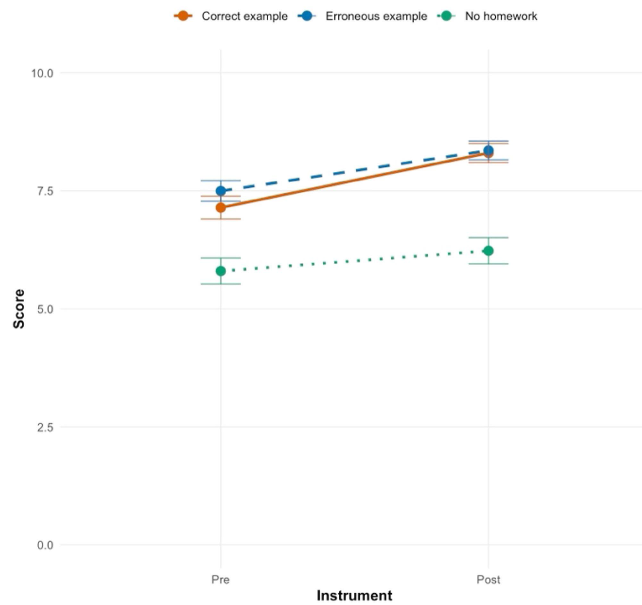

Fig. 5. Interaction plot for the effect of EB tasks.

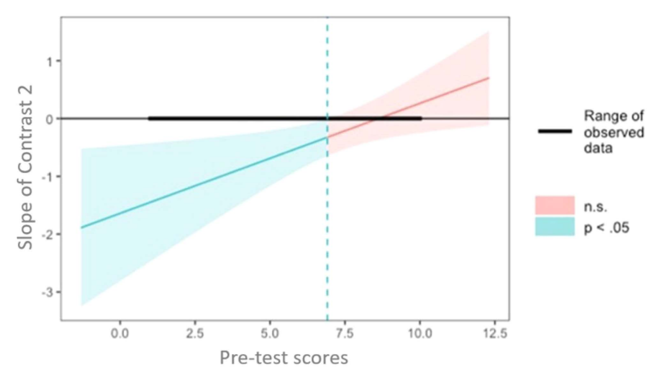

Fig. 6. Confidence interval of Johnson–Neyman technique for the effect of the EB task type.

B. RQ02. LA-Predictive Model for Decimal Number Comprehension

To analyze the potential of using LA to predict the students' decimal number proficiency level reached through the scores obtained in the activities (hereinafter LA-task scores), a multiple

TABLE II
MULTILINEAR REGRESSION ANALYSIS SUMMARY FOR PREDICTING ACADEMIC ACHIEVEMENT IN DECIMAL NUMBERS

	B	SD	*t*	*p*	f^2
Constant	2.02	0.43	4.71	***	
LA scores obtained	0.78	0.05	15.48	***	
Number EB tasks	0.1	0.03	3.58	***	0.08
Gender	–0.37	0.17	–2.14	0.03	0.03

***$p < 0.001$.

linear regression was calculated. Only those students who performed tasks (EB groups) were taken into account. Considering the scores obtained in the EB tasks, a significant regression equation was found ($F(1185) = 269.5$; $p < 0.0001$; $R^2 = 0.59$). Accordingly, the students' scores in the EB tasks can effectively predict the proficiency level on decimal numbers in a subsequent posttest. However, other moderators, such as the number of tasks performed or gender, could adjust the final model presented. In this regard, when the number of tasks done is incorporated into the model, the regression equation was found to improve the prior model ($F(2184) = 149.7$; $p < 0.0001$; $R^2 = 0.62$). Not only is the number of tasks a significant moderator variable (see Table II), but it also improves the efficacy of the model developed. Finally, when gender is also considered in the model, again, a significant regression equation was obtained ($F(3183) = 103.3$; $p < 0.001$; $R^2 = 0.63$). Overall, the inclusion of all these factors improved the final model.

As can be seen in Table II, the participants' predicted decimal number proficiency is equal to 2.02, –0.37 (gender), +0.78 (LA-task scores), and +0.1 (number of EB tasks done), where gender is coded as 0 = male and 1 = female; LA-task scores obtained are measured on a ten-point scale, and the number of EB tasks on a 14-point scale (total number of tasks performed). The male students scored 0.37 more than the females in the posttest. Finally, regardless of gender, the performance of one more activity reveals an improvement of 0.1 on the posttest, and in turn, an improvement in the performance of these activities by one point indicates a subsequent improvement of 0.78 in the final level of performance with decimal numbers. Thus, taking everything into account, gender, the number of tasks performed, and the scores were significant predictors of the post proficiency level.

C. RQ03. Students' Perception About the Designed Tasks

To analyze the last research objective, the results obtained in the LOES-S and RIMM(S) questionnaires were used. These questionnaires were voluntary and anonymously completed by the students who did the tasks via the digital platform at the end of the experimental phase.

First, the reliability of the questionnaires for the sample analyzed was confirmed by Cronbach's alpha. Regarding the LOES-S questionnaire, a Cronbach's alpha higher than 0.9 was obtained ($\alpha = 0.932$), something that also happened in the RIMM(S) test ($\alpha = 0.949$). The results obtained by dimensions and gender can be seen in Table III.

As can be seen, despite the fact that females seem to have scored better on the tasks on the digital platform, no statistical differences were found between the boys and girls for any

TABLE III
DESCRIPTIVE DATA OBTAINED IN LOES-S AND RIMM(S) QUESTIONNAIRE BY GENDER

Test	Dimension	Gender	*N*	*M*	SD
LOES-S	Learning	Male	53	3.16	1.00
		Female	54	3.51	0.98
		Total	107	3.34	1.00
	Quality	Male	53	4.06	0.92
		Female	54	3.96	0.97
		Total	07	4.01	0.94
	Engagement	Male	53	3.08	1.21
		Female	54	3.22	1.07
		Total	107	3.15	1.14
RIMM(S)	Attention	Male	53	3.06	1.24
		Female	54	3.23	1.12
		Total	107	3.15	1.14
	Relevance	Male	53	3.42	1.03
		Female	54	3.68	0.80
		Total	107	3.55	0.93
	Confidence	Male	53	3.18	1.25
		Female	54	3.36	1.08
		Total	107	3.27	1.16
	Satisfaction	Male	53	2.96	1.44
		Female	54	3.44	1.20
		Total	107	3.2	1.34

dimension (Learning, $U = 1125.50$, $p = 0.056$, $r = 0.18$; Quality, $U = 1344.50$, $p = 0.586$, $r = 0.05$; Engagement, $U = 1324.00$, $p = 0.503$, $r = 0.06$; Attention, $U = 1378.00$, $p = 0.739$, $r = 0.03$; Relevance, $U = 1208.50$, $p = 0.161$, $r = 0.13$; Confidence, $U = 1351.00$, $p = 0.616$, $r = 0.05$; Satisfaction, $U = 1168.00$, $p = 0.099$, $r = 0.16$).

Although no gender differences are observed, the comparison between dimensions for each instrument is relevant. Concerning the LOES-S dimensions, the participants rated higher learning compared to engagement ($Z = –3.28$, $p = 0.001$, $r = 0.32$), and quality compared to engagement ($Z = –7.15$, $p < 0.001$, $r = 0.69$) and learning ($Z =–6.50$, $p < 0.001$, $r = 0.63$). These results suggest that students viewed both the design and usefulness of the tasks in a positive light. The results of comparing dimensions from RIMMS would point to the same direction, where it is observed that the relevance dimension has the highest score compared to attention ($Z = –5.05$, $p <0.001$, $r = 0.49$), satisfaction ($Z = –4.08$, $p < 0.001$, $r = 0.39$), and confidence ($Z = –3.91$, $p < 0.001$, $r = 0.38$). However, no difference was observed between confidence and attention ($Z = –1.54$, $p = 0.123$, $r = 0.15$), satisfaction and attention ($Z = –0.12$, $p = 0.904$, $r = 0.01$), and between satisfaction and confidence ($Z = –0.93$, $p = 0.353$, $r = 0.09$). Again, these results highlight that among the dimensions of both instruments, those that receive a better rating from the students are those that refer to the good design of the tasks and their effectiveness, usefulness, and importance for the learners.

VI. DISCUSSION

Despite the widespread presence of technology, adopting it in meaningful ways for teaching and learning is still a work in progress for many educators [2]. In this regard, the implementation of LA techniques not only can be put into practice, but their use can also help educators in their teaching practice [6]. LA allows teachers to gather massive and immediate information and, thus, monitors everything surrounding the teaching–learning process [1], [3], [5]. This is the reason why the effective use of LA has recently been included among teachers' technological competences [20]. However, the use of LA requires more research along the lines of developing effective classroom processes [4] through evidence-based teaching tools and models [7]. This is even more important at levels such as primary education, given the scarce evidence on how to implement them effectively at primary levels [9], [22].

The present study aimed to provide an answer along these lines by proposing an EB teaching sequence in mathematics through a digital platform. Specifically, it focused on decimal numbers due to common and systematic misconceptions when dealing with them [11], the possibility of their persistence over a long period of time [30], and the resulting difficulty to change when they become internalized ideas [31]. Moreover, prioritizing the presence and analysis of the gender gap in mathematics education [35], this study takes advantage of LA's potential to predict these possible differences as previously reported in international assessments, such as PISA 2018 [12] or TIMSS 2019 [13].

According to the results, the tasks were effective, even though students completed them in a short period of time. This supports the idea that task quality matters more than completion time [57] and avoids the possible development of negative attitudes toward school because of exceeding recommended amounts of time spent on homework [58]. Regarding the differences between each condition, considering the pretest scores and disregarding gender, those students who performed the tasks reached a significantly higher academic performance in the posttest. While gender did not significantly moderate the effectiveness of the tasks in this study, previous research has highlighted persistent gender differences in mathematics achievement. International assessments, such as TIMSS and PISA, indicate that males tend to outperform females, though the gap has narrowed over time [12], [13]. Spain shows higher-than-average gender differences in mathematics performance [13]. Beyond overall achievement, recent studies suggest that specific mathematical tasks, such as number comparisons and estimations, present greater challenges for female students, especially when decimals are involved [34]. In this study, both genders benefited equally, suggesting that the task design and digital tools may have minimized these differences. However, LA offers the potential to analyze performance at a more granular level, moving beyond aggregate scores to identify subtle patterns of how students of different genders engage with specific mathematical skills [33]. Future research could explore whether these tools help tailor instructional strategies to reduce gender disparities when they arise.

The two experimental conditions of CE and EE allowed us to see how the effectiveness of each task is moderated by the students' prior knowledge; those students with a low prior level of proficiency benefited more from CE tasks, while there are no significant differences between the tasks' effectiveness in students who obtained an average above 6.75 in the pretest. This is in contrast with authors who defined sequences based on incorrect examples as promoters of better results, without considering the prior level of each student as a moderator [11], [15]. However, other studies have reported the influence of prior knowledge on the success of each type of instruction: having low prior knowledge could explain why CE tasks are more effective than EE tasks in this group of students. EE tasks present a cognitive challenge for students with lower prior knowledge due to the lack of understanding of the concept of the error and its causes [16], [17]. These findings are coherent with constructivist learning perspectives that assume that students interpret and build new knowledge based on their existing cognitive frameworks. When these frameworks are not yet sufficiently developed, tasks that involve processing errors may be harder to use productively.

In addition, the possibility of collecting information related to task resolution through individual logs for each student enables the analysis of the effectiveness of this information to predict their final academic performance [10]. The second RQ was posed taking into consideration the interest that the educational community has in using this information to improve the teaching and learning process [42]. Using the number of activities completed by each student, as well as the students' performance, and considering their gender, we were able to build an effective predictive model of the students' understanding of decimal tasks after the intervention. These findings support using LA as a useful tool for formative assessment.

VII. Conclusion

Even though personalized learning and formative assessment are widely recommended, they are rarely used in practice [19]. However, their integration in the teaching–learning process provides more information about the process itself as well as an improvement in the early diagnosis of students' abilities and difficulties. As a consequence, LA makes it possible to take in-time educational actions without the need to wait until the final summative test [5]. In fact, LA is a useful and necessary technique to be acquired by teachers, since it helps them to collect information more easily and quickly [20], which when done manually can be hard and tedious [18]. Still, its implementation in primary education has been little studied so far [9].

The present study marks a significant advancement in this field of research by exploring the use of LA to improve formative assessments of primary mathematics students, focusing on the design and execution of activities on decimal numbers targeting misconceptions. The implementation of LA within these contents is justified by the large knowledge deficiencies that students commonly have [11]. Based on the results, the use of LA-mediated data makes it possible to predict student performance on a subsequent test [1], [42], [43]. This predictive ability allows teachers to act earlier [5], which may be a key contribution of integrating formative assessment at early ages.

This study combines digital tasks with LA to improve learning and track student progress. Specifically, the use of a Moodle-based digital platform enabled the design of EB tasks combining short-interactive activities and videos with CE and EE. Students who completed the tasks showed greater improvement in their knowledge, being the effectiveness of EB tasks being moderated by the students' prior knowledge. Thus, students with low prior knowledge profit more from CE tasks, though there are no differences when their pretest scores are higher than 6.75. The usefulness of these activities, and their potential to be mediated by the students' prior knowledge, aligns these results with previous studies [16], [17]. Therefore, this issue should be considered, as detailed in the practical implications when tailoring instructional sequences.

Furthermore, while students performed the tasks, different information about student performance was gathered. This information can be useful for teachers to know how the learning process occurs in real time [7], [10], [40], [41]. Moderator variables, such as gender, the number of tasks done, and subsequent scores, are effective predictors of the academic achievement reached, aligned with the conclusions stated in [1] and [42]. The present study has proven that the greater the number of tasks completed, and performance achieved, the higher the academic performance will be. The potential for higher academic performance justifies the implementation of these tasks and their utility for teachers when gathering consistent information as part of their teaching practice.

In addition, the research provides insights into students' perspectives on these digital tasks, highlighting their engagement, interest, and perceived value. Although the tasks may not seem innovative, evaluation results show that students found them well designed and highly useful for their learning. This could be due to the highly focused design that aims to address relevant difficulties for students in this mathematical field, resulting in short-duration homework that avoids repetitive work.

A. *Limitations and Future Studies*

Since the completion of this study, new interesting approaches to analyze in future studies have emerged in line with the results found. First, since the participating schools volunteered to take part in the study, there is a risk of sampling bias: these schools may be more interested in educational innovation and technology-enhanced learning, which could limit the generalizability of the findings to other school contexts.

Second, a limitation in the study configuration is the ecological definition of the No task condition, which emerged organically during the research process. As the assignment of students to this group was not randomized, control over the variable of prior knowledge could not be ensured. Future research would benefit from investigating this issue as a starting condition by proposing alternatives to the performance of the tasks. It would also be interesting for future research to include a comparison with a traditional pencil-and-paper group. This comparison could provide valuable information on the effectiveness of different learning methods, further improving our understanding of educational strategies in various settings.

Moreover, considering the results obtained, to replicate this study, but carrying out all the tasks as classroom activities instead of homework, could be of interest as it would allow us to verify if the benefits of EB tasks extend to all students, even those who usually do not complete their homework at home. On the other hand, developing similar tasks with other mathematical contents, or even other areas or educational levels, could lead to relevant conclusions in the educational community. Furthermore, a longer study incorporating more complex EE tasks and interactive activities could offer new insights into students' long-term engagement and learning outcome. While the GeoGebra activities are interactive, most of the tasks were not, due to the limitations of the LMS Moodle, which, despite being widely used, presents important constraints for the development of mathematical tasks. Future research could address this by incorporating a higher degree of interactivity in the sessions. Longer term studies could help assess the lasting impact of CE and EE tasks, as well as whether their effectiveness continues to depend on students' prior knowledge levels.

Finally, given that the study has been developed in primary education, but contains practical implications for teachers, evaluating instructional sequences at the university level of teacher training on the use of LA-based tools could open a new line of research of interest and importance for the scientific and educational community.

B. *Implications for Practice*

This study aims to contribute to the educational community with empirical evidence concerning the use of LA in primary education, a domain where such evidence has been relatively scarce. LA can support teachers in monitoring and guiding students' understanding of decimal numbers through formative assessment. By using the information provided by Moodle, a platform widely used in educational environments for its cost effectiveness, teachers can identify and address specific student misconceptions in real time, leading to more personalized and effective teaching. Furthermore, the integration of predictive LA as part of this approach could yield significant educational benefits, aligning with previous studies in other mathematical contents, areas, or educational levels [5], [8], [9]. However, to the best of our knowledge, no studies have reported similar predictive models with primary school students. This data-driven assessment-based approach represents an important step forward in creating responsive and effective educational environments for mathematics education and, in particular, decimal numbers, while allowing teachers to achieve this formative assessment through LA-mediated data collection on a semiautomatic, predictive, and daily basis [1], [10], [19].

Based on the results, educators designing instructional sequences should consider that CE tasks tend to be more effective for students with lower levels of prior knowledge, whereas EE tasks may be more appropriate for those with a stronger foundation. These recommendations are supported by the greater cognitive demand associated with EE tasks.

Finally, using two validated instruments, LOES-S and RIMMS, we evaluated the students' perception toward the instructional sequence that they completed in the experimental phase (RQ.03). The results show a moderate value in the interest dimension, which is expected considering that it is an evaluation of school duties. Therefore, one of the most valuable results comes from the participants' appreciation of the quality and relevance of the tasks, which would be associated with positive impact on their learning. In the same vein, results from a systematic review [44] would point in this direction, as they underlined the greater effectiveness of this type of digital task compared to traditional homework. Overall, the tasks not only supported academic achievement but were also perceived as effective by the primary school students.

Acknowledgment

The authors would like to express their sincere gratitude to Dr. M. C. Sánchez for her assistance in reviewing and improving the writing of this article. Her comments and suggestions greatly contributed to enhancing the clarity and overall quality of the final manuscript.

References

[1] J. Stanja, W. Gritz, J. Krugel, A. Hoppe, and S. Dannemann, "Formative assessment strategies for students' conceptions—The potential of learning analytics," *Brit. J. Educ. Technol.*, vol. 54, no. 1, pp. 58–75, Jan. 2022, doi: 10.1111/bjet.13288.

[2] K. Pelletier et al., *2021 EDUCAUSE Horizon Report Teaching and Learning Edition*. Boulder, CO, USA: Educause, 2021.

[3] P. Long, G. Siemens, G. Conole, and D. Gašević, *LAK '11: Proceedings of the 1st International Conference on Learning Analytics and Knowledge*. New York, NY, USA: Assoc. Comput. Mach., 2011.

[4] A. K. Dubé and R. Wen, "Identification and evaluation of technology trends in K-12 education from 2011 to 2021," *Educ. Inf. Technol.*, vol. 27, no. 2, pp. 1929–1958, Mar. 2022, doi: 10.1007/s10639-021-10689-8.

[5] J. A. Rodríguez-Martínez, J. A. González-Calero, J. del Olmo-Muñoz, D. Arnau, and S. Tirado-Olivares, "Building personalised homework from a learning analytics based formative assessment: Effect on fifth-grade students' understanding of fractions," *Brit. J. Educ. Technol.*, vol. 54, no. 1, pp. 76–97, Jan. 2023, doi: 10.1111/bjet.13292.

[6] I. Amarasinghe, K. Michos, F. Crespi, and D. Hernández-Leo, "Learning analytics support to teachers' design and orchestrating tasks," *J. Comput. Assist. Learn.*, vol. 40, pp. 2416–2431, Jul. 2022, doi: 10.1111/jcal.12711.

[7] D. Gašević, S. Greiff, and D. W. Shaffer, "Towards strengthening links between learning analytics and assessment: Challenges and potentials of a promising new bond," *Comput. Hum. Behav.*, vol. 134, Sep. 2022, Art. no. 107304, doi: 10.1016/j.chb.2022.107304.

[8] X. Du, J. Yang, B. E. Shelton, J.-L. Hung, and M. Zhang, "A systematic meta-review and analysis of learning analytics research," *Behav. Inf. Technol.*, vol. 40, no. 1, pp. 49–62, Jan. 2021, doi: 10.1080/0144929X.2019.1669712.

[9] K.-C. Li and B. T.-M. Wong, "Trends of learning analytics in STE(A)M education: A review of case studies," *Interact. Technol. Smart Educ.*, vol. 17, no. 3, pp. 323–335, Jun. 2020, doi: 10.1108/ITSE-11-2019-0073.

[10] T. S. Justin, R. Krishnan, S. Nair, and B. S. Samuel, "Learners' performance evaluation measurement using learning analytics in Moodle," in *Proc. Inf. Commun. Technol. Competitive Strategies*, 2022, pp. 931–942, doi: 10.1007/978-981-16-0739-4_87.

[11] K. Durkin, "The effectiveness of incorrect examples and comparison when learning about decimal magnitude," Ph.D. dissertation, Dept. Psychology, Vanderbilt Univ., Nashville, TN, USA, 2012.

[12] *PISA 2018—Programa para la Evaluación Internacional de los Estudiantes*. Organization for Economic Co-operation and Development, Paris, France, 2019.

[13] I. V. S. Mullis, M. O. Martin, P. Foy, D. L. Kelly, and B. Fishbein, *TIMSS 2019 International Results in Mathematics and Science*. Chestnut Hill, MA, USA: TIMSS & PIRLS International Study Center, 2020.

[14] C. J. Fitzsimmons, K. Morehead, C. A. Thompson, M. Buerke, and J. Dunlosky, "Can feedback, correct, and incorrect worked examples improve numerical magnitude estimation precision?," *J. Exp. Educ.*, vol. 91, no. 1, pp. 20–45, Jan. 2021, doi: 10.1080/00220973.2021.1891009.

[15] T.-H. Huang, Y.-C. Liu, and C.-Y. Shiu, "Construction of an online learning system for decimal numbers through the use of cognitive conflict strategy," *Comput. Educ.*, vol. 50, no. 1, pp. 61–76, 2008, doi: 10.1016/j.compedu.2006.03.007.

[16] D. M. Adams et al., "Using erroneous examples to improve mathematics learning with a web-based tutoring system," *Comput. Hum. Behav.*, vol. 36, pp. 401–411, 2014, doi: 10.1016/j.chb.2014.03.053.

[17] Z. Yang, M. Wang, H. N. H. Cheng, S. Liu, L. Liu, and T.-W. Chan, "The effects of learning from correct and erroneous examples in individual and collaborative settings," *Asia-Pacific Educ. Res.*, vol. 25, no. 2, pp. 219–227, Apr. 2016, doi: 10.1007/s40299-015-0253-2.

[18] A. Pardo, J. Jovanovic, S. Dawson, D. Gašević, and N. Mirriahi, "Using learning analytics to scale the provision of personalised feedback," *Brit. J. Educ. Technol.*, vol. 50, no. 1, pp. 128–138, Jan. 2019, doi: 10.1111/bjet.12592.

[19] R. H. Sagarika, R. Kandakatla, and A. Gulhane, "Role of learning analytics to evaluate formative assessments: Using a data driven approach to inform changes in teaching practices," *J. Eng. Educ. Transformations*, vol. 34, pp. 550–556, Jan. 2021, doi: 10.16920/jeet/2021/v34i0/157212.

[20] F. Caena and C. Redecker, "Aligning teacher competence frameworks to 21st century challenges: The case for the European digital competence framework for educators (Digcompedu)," *Eur. J. Educ.*, vol. 54, no. 3, pp. 356–369, Sep. 2019, doi: 10.1111/ejed.12345.

[21] K. Pelletier et al., *2022 EDUCAUSE Horizon Report—Teaching and Learning Edition*. Boulder, CO, USA: Educause, 2022.

[22] S. Tirado-Olivares, A. Bueno-Baquero, C. López-Fernández, R. Mínguez-Pardo, and R. Cózar-Gutiérrez, "Revisión de la literatura sobre el uso de Learning Analytics en el rendimiento académico de estudiantes de pregrado: Impresiones iniciales," in *Educar Para Transformar: Innovación Pedagógica, Calidad y TIC En Contextos Formativos*, L. Molina-García, D. Cobos-Sanchiz, E. López-Meneses, A. J. Martínez, and A.-H. Martín-Padilla, Eds., Madrid, Spain: Dykinson, 2023, pp. 2511–2521.

[23] R. Rundquist, K. Holmberg, J. Rack, Z. Mohseni, and I. Masiello, "Use of learning analytics in K–12 mathematics education," *J. Learn. Anal.*, vol. 11, no. 3, pp. 174–191, Dec. 2024, doi: 10.18608/jla.2024.8299.

[24] I. S. M. Ramli, S. M. Maat, and F. Khalid, "Learning analytics in mathematics: A systematic review," *Int. J. Acad. Res. Progressive Educ. Develop.*, vol. 8, no. 4, pp. 436–449, 2019, doi: 10.6007/IJARPED/v8-i4/6563.

[25] L. DeSmet, J. Grégoire, and C. Mussolin, "Developmental changes in the comparison of decimal fractions," *Learn. Instruct.*, vol. 20, pp. 521–532, 2010.

[26] K. C. Irwin, "Using everyday knowledge of decimals to enhance understanding," *J. Res. Math. Educ.*, vol. 32, no. 4, pp. 399–420, 2001.

[27] L. B. Resnick, P. Nesher, F. Leonard, M. Magone, S. Omanson, and I. Peled, "Conceptual bases of arithmetic errors: The case of decimal fractions," *J. Res. Math. Educ.*, vol. 20, no. 1, pp. 8–27, 1989, doi: 10.2307/749095.

[28] K. Stacey, S. Helme, V. Steinle, A. Baturo, K. Irwin, and J. Bana, "Preservice teachers' knowledge of difficulties in decimal numeration," *J. Math. Teacher Educ.*, vol. 4, pp. 205–225, Feb. 2001, doi: 10.1023/A:1011463205491.

[29] B. Rittle-Johnson, R. S. Siegler, and M. W. Alibali, "Developing conceptual understanding and procedural skill in mathematics: An iterative process," *J. Educ. Psychol.*, vol. 93, pp. 346–362, 2001.

[30] A. Eryilmaz, "Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion," *J. Res. Sci. Teach.*, vol. 39, no. 10, pp. 1001–1015, Dec. 2002, doi: 10.1002/tea.10054.

[31] M. W. Alibali and P. G. Sidney, "Variability in the natural number bias: Who, when, how, and why," *Learn. Instruct.*, vol. 37, pp. 56–61, 2015, doi: 10.1016/j.learninstruc.2015.01.003.

[32] S. Vosniadou and L. Verschaffel, "Extending the conceptual change approach to mathematics learning and teaching," *Learn. Instruct.*, vol. 14, no. 5, pp. 445–451, 2004, doi: 10.1016/j.learninstruc.2004.06.014.

[33] X. Vamvakoussi and S. Vosniadou, "How many decimals are there between two fractions? Aspects of secondary school students' understanding of rational numbers and their notation," *Cogn. Instruct.*, vol. 28, pp. 181–209, Apr. 2010, doi: 10.1080/07370001003676603.

[34] S. L. Martinie, "Decimal fractions: An important point," *Math. Teach. Middle Sch.*, vol. 19, no. 7, pp. 420–429, 2014, doi: 10.5951/mathteacmiddscho.19.7.0420.

[35] G. Leder and S. Lubienski, "Large-scale test data: Making the invisible visible," in *Diversity in Mathematics Education. Mathematics Education Library*. Cham, Switzerland: Springer, 2015, pp. 17–40.

[36] C. Cascella, C. Giberti, and G. Bolondi, "An analysis of differential item functioning on INVALSI tests, designed to explore gender gap in mathematical tasks," *Stud. Educ. Eval.*, vol. 64, 2020, Art. no. 100819, doi: 10.1016/j.stueduc.2019.100819.

[37] P. Rosário, J. Cunha, T. Nunes, A. R. Nunes, T. Moreira, and J. C. Núñez, "'Homework should be …but we do not live in an ideal world': Mathematics teachers' perspectives on quality homework and on homework assigned in elementary and middle schools," *Front. Psychol.*, vol. 10, 2019, Art. no. 224, doi: 10.3389/fpsyg.2019.00224.

[38] M. L. Lunsford and M. Pendergrass, "Making online homework work," *Probl., Resour., Issues Math. Undergraduate Stud.*, vol. 26, no. 6, pp. 531–544, 2016, doi: 10.1080/10511970.2015.1110219.

[39] I. Kliziene, G. Taujanskiene, A. Augustiniene, B. Simonaitiene, and G. Cibulskas, "The impact of the virtual learning platform EDUKA on the academic performance of primary school children," *Sustainability*, vol. 13, no. 4, Feb. 2021, Art. no. 2268, doi: 10.3390/su13042268.

[40] I. Ros Martínez de Lahidalga, "Moodle, la plataforma para la enseñanza y organización escolar," *Ikastorratza, e-Revista de Didáctica*, vol. 2, pp. 1–12, 2008.

[41] S. Yassine, S. Kadry, and M.-A. Sicilia, "A framework for learning analytics in moodle for assessing course outcomes," in *Proc. IEEE Glob. Eng. Educ. Conf.*, Apr. 2016, pp. 261–266, doi: 10.1109/EDUCON.2016.7474563.

[42] O. Bulut et al., "Standing on the shoulders of giants: Online formative assessments as the foundation for predictive learning analytics models," *Brit. J. Educ. Technol.*, vol. 54, no. 1, pp. 19–39, Jan. 2023, doi: 10.1111/bjet.13276.

[43] N. Sghir, A. Adadi, and M. Lahmer, "Recent advances in predictive learning analytics: A decade systematic review (2012–2022)," *Educ. Inf. Technol.*, vol. 28, no. 7, pp. 8299–8333, Jul. 2023, doi: 10.1007/s10639-022-11536-0.

[44] P. Magalhães, D. Ferreira, J. Cunha, and P. Rosário, "Online vs traditional homework: A systematic review on the benefits to students' performance," *Comput. Educ.*, vol. 152, 2020, Art. no. 103869, doi: 10.1016/j.compedu.2020.103869.

[45] P. Thompson, "Didactic objects and didactic models in radical constructivism," *Symbolizing, Model. Tool Use Math. Educ.*, pp. 197–220, 2002, doi: 10.1007/978-94-017-3194-2_12.

[46] L. Branchetti, A. Lemmo, F. Ferretti, A. Maffia, and F. Martignone, "Students' difficulties dealing with number line: A qualitative analysis of a question from national standardized assessment," in *Quaderni Di Ricerca in Didattica (Mathematics)*, C. Sabena and B. Di Paola, Eds., Aosta, Italy: Gruppo di Ricerca sull'Insegnamento/Apprendimiento delle Mathematiche, Jul. 2015, pp. 143–150.

[47] R. Mínguez-Pardo, J. Del Olmo-Muñoz, J. A. González-Calero, D. Arnau, and M. C. Sánchez-Pérez, "Diagnóstico de errores comunes en el aprendizaje de los números decimales en Educación Primaria," in *Investigación en Educación Matemática XXV*, T. F. Blanco, C. Núñez-García, M. C. Cañadas, and J. A. Gonz´lez-Calero, Eds., Spain: SEIEM, 2022, pp. 615. [Online]. Available: https://www.seiem.es/docs/actas/25/ActasXXVSEIEM.pdf

[48] L. V. Hedges, "Challenges in building usable knowledge in education," *J. Res. Educ. Effectiveness*, vol. 11, no. 1, pp. 1–21, 2018, doi: 10.1080/19345747.2017.1375583.

[49] J. Leppink, "The question-design-analysis bridge," in *Statistical Methods for Experimental Research in Education and Psychology*. Berlin, Germany: Springer, 2019, pp. 3–21.

[50] R. H. Kay and L. Knaack, "Assessing learning, quality and engagement in learning objects: The learning object evaluation scale for students (LOES-S)," *Educ. Technol. Res. Develop.*, vol. 57, no. 2, pp. 147–168, Apr. 2009, doi: 10.1007/s11423-008-9094-5.

[51] N. Loorbach, O. Peters, J. Karreman, and M. Steehouder, "Validation of the instructional materials motivation survey (IMMS) in a self-directed instructional setting aimed at working with technology," *Brit. J. Educ. Technol.*, vol. 46, no. 1, pp. 204–218, Jan. 2015, doi: 10.1111/bjet.12138.

[52] J. M. Keller, "Development and use of the ARCS model of instructional design," *J. Instructional Develop.*, vol. 10, no. 3, pp. 2–10, Sep. 1987, doi: 10.1007/BF02905780.

[53] K. Li and J. M. Keller, "Use of the ARCS model in education: A literature review," *Comput. Educ.*, vol. 122, pp. 54–62, Jul. 2018, doi: 10.1016/j.compedu.2018.03.019.

[54] A. F. Hayes, *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach* (ser. Methodology in the Social Sciences), 3rd ed. New York, NY, USA: Guilford Publications, 2022.

[55] A. F. Hayes and A. K. Montoya, "A tutorial on testing, visualizing, and probing an interaction involving a multicategorical variable in linear regression analysis," *Commun. Methods Meas.*, vol. 11, no. 1, pp. 1–30, Jan. 2017, doi: 10.1080/19312458.2016.1271116.

[56] R Core Team, "*R: A language and environment for statistical computing*, Vienna, Austria: R Foundation for Statistical Computing, 2023.

[57] J. C. Núñez, B. Regueiro, N. Suárez, I. Piñeiro, M. L. Rodicio, and A. Valle, "Student perception of teacher and parent involvement in homework and student engagement: The mediating role of motivation," *Front. Psychol.*, vol. 10, Jun. 2019, Art. no. 1384, doi: 10.3389/fpsyg.2019.01384.

[58] M. N. Stevenson, "Homework and academic achievement: A meta-analysis examining impact," Ed.S. thesis, Sch. Educ. Health Sci., Univ. Dayton, Dayton, OH, USA, 2021.

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