Training arithmetic and orthography on a web-based and socially-interactive learning platform

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***Abstract*—**Reading and writing (i.e., literacy) as well as numerical skills (i.e., numeracy) are key competencies in modern knowledge societies. Although digital media is nowadays part and parcel of children's and youngsters' everyday life, literacy and numeracy education is still largely based on paper-pencil approaches. To overcome this gap and to complement formal education by more informal learning settings, we developed, implemented and evaluated a web-based and socially-interactive learning platform. The platform hosts several learning games and aims at enhancing secondary school students' orthography and arithmetic skills. In a pilot evaluation (Study 1), we observed the orthography games to specifically corroborate 5th and 6th graders spelling performance. On the other hand, we only found general intervention effects with respect to arithmetic. To supplement these results by the perspective of those who may wish to use the platform for educational purposes, we also conducted a survey among teachers (Study 2). The survey provided an informative basis on the estimated difficulty and relevance of learning topics in orthography and arithmetic as well as on the use and acceptance of computer-supported teaching methods in general. Thereby, we gained important indications on how to further improve the learning platform and the embedded games. Taken together, the results of Study 1 and 2 were promising and revealed that computer-supported learning environments may be used to corroborate literacy and numeracy skills in formal education.

***Keywords*—**arithmetic, digital learning games, literacy, numeracy, orthography.

The current research was supported by the Science Campus Tuebingen (Cluster 1, TP1 in the first phase; Cluster 8 TP1 and 4 in the second phase) providing funding to Korbinian Moeller and Hans-Christoph Nuerk supporting Stephanie Roesch, Stefanie Jung, and Stefan Huber. Moreover, we thank the participating schools for their collaboration and Lauren Johnstone for proofreading of the manuscript.

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I. Introduction

A. *The importance of numeracy and literacy*

Numeracy and literacy (i.e., basic numerical and arithmetical skills as well as reading and writing abilities) are not only basic skills acquired during school education. In fact, they constitute key competencies important for a successful life in post-industrial knowledge societies of the 21st century.

Against this background it seems reasonable that failing to acquire basic numeracy and literacy comes with severe disadvantages for the affected individuals. Poor numerical or arithmetical skills, for instance, have been shown to adversely influence an individual's career advancements and health prospects [1]. This effect also applies to insufficient literacy skills which increase an individual's risk for school dropout, low educational achievement and unemployment [2]. Moreover, children with poor reading or writing skills appear to be aware of their fewer opportunities and the societal relevance of literacy skills. As a consequence, they tend to be more inclined to suffer from behavioral and emotional problems (e.g., [3]).

Insufficient numeracy and literacy, however, are not only associated with individual disadvantages; they also lead to immense socio-economic costs for the whole society as a whole [4], [5]. In case of deficient numeracy, these costs have been estimated to accumulate to up to £2.4 billion per annum for the United Kingdom [6]. Moreover, the Organization for Economic Co-operation and Development [7] estimated that "an improvement of one-half standard deviation in mathematics and science performance at the individual level implies, by historical experience, an increase in annual growth rates of GDP [gross domestic product] per capita of 0.87%" (p. 17). Regarding inadequate literacy, the KPMG Foundation [8] estimated the annual costs to range between £45,000 and £53,000 per individual, working out to a total sum of £1.73 to £2.05 billion every year.

These results highlight that numeracy and literacy are not only relevant on the individual but also on the societal level. Successful numeracy and literacy education as well as effective training programs for those students who show poorer levels of performance (e.g., dyscalculic and dyslexic children) are, thus, of prime importance.

B. Digital learning games in numeracy and literacy education

Over the last decades, digital media have become more and more important. Today, they are part and parcel of children's and youngsters' everyday life. Digital media influence free-time activities, interactions, and peer group communication considerably. However, with respect to formal education or remediation, teaching of numeracy and literacy is still largely based on textbooks and paper-pencil approaches. Thus, there is a considerable discrepancy between the use of digital media for leisure time activities and for educational purposes at school (e.g., for numeracy and literacy education). To overcome this gap, an increasing number of commercial and non-commercial digital learning games has been developed and are now available on the market. This variety of games and their different denotations, such as e.g., serious games, educational games, game-based learning or edutainment, complicates the discussion on and the unequivocal distinction of digital learning games [9]. Yet, all concepts have at least one aspect in common: digital learning games aim at combining positive aspects of gaming (i.e., motivation and excitement) with serious educational content. This combination can provide an engaging learning environment suitable for the generation of 'digital natives'.

Unfortunately, only a minority of learning games were developed considering recent research findings (e.g., in domains such as numerical cognition or educational sciences) and evaluated scientifically. However, there already are some promising digital learning games addressing numeracy and literacy. These offer either both arithmetic and orthography trainings (e.g., Lernwerkstatt: http://www.lernwerkstatt.de; Dybuster: http://www.dybuster.com) or solely cover reading/writing (e.g., Tintenklex: http://www.legasthenie-software.de) and numerical skills (e.g., The Number Race: http://www.lacourseauxnombres.com; Meister Cody: https://www.meistercody.com; for an overview see also [10]). In very few cases, positive learning effects were evaluated empirically (Orthography: e.g., [11], Arithmetic: e.g., [12], [13]).

Irrespective of the potential benefits of digital learning games in general, their effectiveness seems to depend on certain game characteristics, such as the clarity of instructions, didactic principles as well as playful design elements [14]. The way contents are presented on visual interfaces (e.g., regarding color coding; [15], [16]) as well as the design of interactions seems to be relevant, too [17], [18]. With respect to cognitive load, these principles are particularly important to learners with little prior knowledge on the topic [19], [20].

Interestingly, digital learning games tend to be more effective when played in groups (for a meta-analysis see [21]), as players seem to favor the opportunity to interact and compete with each other [22]. This requires comparably skilled opponents to ensure that players continue to exert themselves and play for longer periods of time [23]. Games with unmatched opponents may only increase the enjoyment of players with a higher skill level, whereas lower skilled opponents are likely to become frustrated by being defeated constantly. Thus, digital learning games seem to be most effective when they are socially-interactive and offer the possibility to match opponents according to their skill level.

Nevertheless, digital learning games are not necessarily more motivating than classic learning approaches [21]. Detailed specifications when and where to play, for instance, are claimed to reduce students' motivation to engage in the game. They lead to a lack of experienced control and thereby hamper the opportunity to be involved in the game world. Digital learning games should therefore offer the possibility to be used both individually and flexibly.

Individuality and flexibility are particularly well served by web-based learning games. Via the internet, these games can be played almost anywhere, anytime, and across different devices (e.g., on a personal computer, tablet or smartphone) either as stand-alone learning application or as part of a more comprehensive 'learning platform'. The term 'learning platform' usually refers to a software system (cf. [24]) that (i) provides a variety of learning materials or learning games, (ii) offers administrative tools for teachers (e.g., user administration, evaluation methods), and (iii) allows for communication among users (e.g., on a forum or chat). By this means, learning becomes personalized and flexible but is, nevertheless, accompanied by teachers, psychologists or specialists of other domains.

Based on this knowledge on the effectiveness of digital learning games, the present project aimed at designing, implementing, and evaluating a web-based and socially-interactive learning platform hosting various learning games for arithmetic and orthography. In the following section, key features of the learning platform as well as the embedded learning games will be described. Subsequently, the results of a pilot evaluation (Study 1) of the learning platform will be presented. This pilot evaluation examined whether 5th and 6th graders were able to improve their arithmetic and orthography performance by playing the learning games. Insights gained from the pilot evaluation are supplemented by results of a survey among teachers (Study 2) which takes the teachers' experiences and perspectives into account. These results provide an informative basis on (i) the difficulty and relevance of several learning topics in the field of arithmetic and orthography as well as (ii) the use and acceptance of computer-supported teaching methods in general.

II. A Web-based Learning Platform for Arithmetic and Orthography

The web-based and socially-interactive learning platform for arithmetic and orthography (http://lernplattform.iwm-kmrc.de)[1] was designed and implemented in an

[1] Please note that the link may temporarily be not available because of ongoing work on the learning platform.

interdisciplinary collaboration between computer scientists, psychologists, and linguists of the University of Tuebingen and the Knowledge Media Research Center in Tuebingen. The learning platform hosts several learning games and aims at enhancing secondary school students' arithmetic and orthography skills. Initially, we will describe the features of the learning platform before we turn to the presentation of the embedded learning games (a detailed description of the learning platform can be found in [25]).

A. *Features of the learning platform*

The learning platform contains several components to personalize its use and promote social interaction (see Fig. 1).

i. On a front page, students are invited to register (Fig. 1, 'User Login') and are informed about which users are logged in at the moment and who joined the community recently (Fig. 1, 'Logged in users' and 'New users'). Setting up such profiles offers the opportunity to monitor and evaluate students' learning progress.
ii. Subsequent to the registration, an individual profile page is generated (Fig. 1, 'Mein Konto'). Here, students have the possibility to add personal information (e.g., age, gender, preference for school subjects, etc.) without being obliged to disclose personal data. These profiles aim at enhancing an exchange among students.
iii. Moreover, the platform provides a chat forum to allow for communication among students and offer the possibility to contact psychologists and programmers when necessary (Fig. 1, 'Forum').
iv. From the front page, all hosted learning games can be accessed (Fig. 1, 'Spielen'). These games were designed as browser games to facilitate cross-platform playability on personal computers, smartphones and tablets. Thus, all games are playable across platforms, anytime, and anywhere (e.g., at school or at home).

To provide all these features implemented on the learning platform, client-server architecture based on the Google Web Toolkit (GWT) was established. GWT is a development kit that allows for implementing complex browser-based applications. It comprises a Java-to-Javascript compiler allowing for the development of rich internet applications solely written in Java. Thus, large application development becomes manageable. Additionally, GWT comprises a large library of widgets and panels as well as several built-in methods to communicate with a server (e.g., remote procedure calls which were used for the implementation of the present platform). All user data generated while playing the games (e.g., textual input, touchpad/mouse movement and current game states) are logged on a database server system that runs the object-relational database management system PostgreSQL. These logs are archived over longer periods of time and allow for analyzing gamers' performance and development [26].

B. *Learning games for arithmetic and orthography*

Prior to the development of the learning games, numerical and orthographic skills of more than n=400 5th and 6th graders were assessed. Thereby, individual difficulties and developmental trajectories for these skills could be identified [27], [28]. Based on these data, four numerical and four spelling games were developed and implemented on the learning platform.

A core feature of these games is their social interactivity which comprises two components: (i) First, almost all games are multiplayer games and can be played against up to 4 other players or a computer-controlled opponent. Thus, players who balance best between both fast as well as accurate responses will gain more score points than their opponent (i.e., the computer or another player) and will finally win the game. (ii) Second, an integrated chat function is assessable and enables children to communicate with each other while playing. Moreover, in order to develop most effective and individually tailored interventions, all learning games are based on both theoretical considerations as well as recent findings in the relevant domains.

Fig. 1: Opening page of the web-based learning platform.

The numerical games, which will be described in the following paragraph, were designed in line with our recent results regarding number processing e.g., [28] - [30].

i. The 'Number Line Game' was designed to train children in mapping numbers and space [30]. In this game, students have to identify the correct position of a given number (e.g., 26) by marking a plain number line with their mouse cursor. Once a student has marked a position on the number line, slower opponents cannot place their marker at the or around same location (i.e., 5% deviation). This approach was chosen to provoke players balance between both accuracy and speed.
ii. In the game 'Partner Number' addition problems are trained. Students are asked to choose one out of four given numbers (e.g., 2) and then to select the corresponding number that adds up to 10 (i.e., 8) out of several response options. The player who selects the correct solution first will win a score point and the next task is started. Due to this procedure, players are again requested to answer both accurately and quickly.
iii. The 'Carry Game' extends the training of additions by specifically focusing on carry-over operations. To solve this kind of operation, the following solution strategy is trained: adding up to the next decade before adding the remaining rest of the addend. At first, students choose one out of three addition problems (e.g., 3 + 8). Then, they are asked to solve the selected problem in two steps. First, they need to identify and select the number that needs to be added to the first summand (i.e., 3) to add up 10 (solution: 7). Second, they are required to indicated which number remains to be added to result in the correct solution of the problem (i.e., 11; solution: 1). The player who is the fastest to solve this task correctly will win a score point.
iv. The game 'Multiplication' was designed to enhance students' ability to solve multiplications. To pursue this aim, a multiplication result is presented to students (e.g., 14). Subsequently, they are requested to select the corresponding multiplication problem (i.e., 7 x 2) faster than their opponents out of several response options.

The four orthography games designed for the learning platform focus on different aspects of German spelling rules and consider a detailed analyses of the relevant linguistic characteristics on which spelling conventions are based, including phonological (e.g., perceptual sensitivity of vowel duration) and morphological aspects (e.g., word-formation).

i. In German, double consonants (e.g., tt, nn, etc.) usually follow short vowels. As a consequence, students should be able to identify short and long vowels to apply this rule correctly [31], [32]. The 'Gemination Game' aims at enhancing students' awareness of short and long vowels in three phases. First, students are requested to identify the length of the vowel in an auditorily presented word (e.g., tall) by a click on the respective symbol (i.e., an exploding ball for 'short vowel' or a little man pulling a rope for 'long vowel'). The second phase comprises a mini-game in which coins depicting double consonants are falling down from the top of the screen. Students are asked to collect as many coins as possible that show the same double consonant as in the word presented in the first phase. For each collected coin players will gain a score point. Finally in phase three, students are requested to spell the target word correctly by typing it in.
ii. The game 'LeTris' also trains the production of correct spellings and was designed in the style of the well-known game 'Tetris'. Instead of geometric figures, letters start to fall down from the top of the screen after a word was presented auditorily. Students need to arrange these letters according to their order in the presented word. As in Tetris, the line of letters clears away and score points are gained when the word is spelled correctly whereas they remain on the screen when the word was spelled incorrectly. As a consequence, the more words are spelled incorrectly the more letters are piling up, finally resulting in game over.
iii. Knowledge about word families (i.e., words that share the same root or morpheme such as read, readable, etc.) is associated with literacy performance [32], [33]. As all words belonging to a word family are spelled similarly, word families might be used to derive the spelling of related words. Accordingly, the game 'Word Families' aims at enhancing this ability in students. First, a target word is presented to students (e.g., family) followed by several other words of which some are part of the same word family. Students are requested to remember as many of only those words belonging to the word family of the target word (e.g., familiarity, familiar, etc.) and are later asked to type them in.
iv. The game 'Building Blocks' also aims at enhancing students' knowledge about word families and was designed as choice-reaction task. First, students have to select one out of four morphemes (e.g., new). Next, they are requested to mark as many of the words presented in a box below which belong to the same word family (e.g., newcomer, news, etc.). As this game was again designed as multiplayer game, a player will score a point when he or she responds both quickly and accurately.

I. Study 1: Pilot evaluation of the web-based learning platform

Study 1 evaluated whether 5th and 6th graders can improve their arithmetic and orthography performance by playing the learning games hosted on the web-based learning platform. Moreover, this first rollout to the field also targeted at informally testing the technical and organizational conditions of schools as well as the overall acceptance of the learning platform.

A. Method

1) Participants

Thirty-one 5th or 6th graders took part in this pilot investigation. The students were recruited from two classes of two different public secondary schools (German 'Hauptschule') in Baden-Wuerttemberg, Germany. In both classes 5th and 6th graders were taught together. As some students did not complete all training and testing sessions, data analysis of the arithmetic and spelling training is based on 24 (10 female) and 23 students (9 female), respectively. Written consent was obtained of all parents and schools as well as assertions of all participating children.

2) Procedure

A cross-over design was applied in which the arithmetic training served as a control condition for the orthography training and vice versa. One of the two classes received three training sessions on orthography first, followed by three sessions on arithmetic (group 1), while the other class started with three arithmetic sessions and continued with three sessions on orthography (group 2). Training took place once a week at school over a period of up to six weeks. Trainings session lasted no longer than 45 minutes. During each arithmetic/orthography training session, children played three learning games; either 'Gemination Game', 'Word Families' and 'Word Building Blocks' for orthography or 'Multiplication', 'Partner Number' ,and 'Carry Game' for arithmetic. Each game lasted for about 10 minutes.

Students playing against each other were selected by class teachers who matched opponents according to their individual skill level. This procedure was chosen to balance the chance to win a game, which was argued to be necessary to maintain students' motivation to play (e.g., [23]).

Computer equipment of the participating schools was inspected before the study took place. As schools turned out to be insufficiently equipped for the training on the web-based learning platform (e.g., restricted upload capacities of max. 128 kB/s due to low bandwidth, problems to resort to local servers), a so-called mobile classroom comprising one laptop for each student was set up. These laptops were connected in pairs via LAN cables, so that one laptop served as client whereas the other hosted the whole learning platform.

3) Assessment

To monitor students' learning progress, their arithmetic and orthography skills were assessed at the beginning (T1), after the first training block of either arithmetic or orthography (T2) as well as after the second training block was completed.

To assess students' arithmetic skills, a speeded paper-pencil test was used. All four arithmetic operations were considered in both either easy or difficult problems: (1) addition easy - 18 no-carry problems (e.g., 21 + 7), (2) addition difficult – 18 problems, 9 of which required a carry operation (e.g., 7 + 6), (3) subtraction easy – 15 no-borrow problems (e.g., 29 - 7), (4) subtraction difficult – 15 problems, 7 of which required a borrow operation (e.g., 15 - 7), (5) multiplication easy – 28 single-digit problems (e.g., 3 x 4), (6) multiplication difficult – 14 problems in which two-digit numbers were multiplied by one-digit numbers (e.g., 14 x 3), (7) division easy – 28 problems with one-digit divisors and results (e.g., 12 : 3), (8) division difficult – 14 problems with one- and two-digit divisors and results (e.g., 48 : 3 or 144 : 8). All tasks of the easy level were conducted with a time limit of 30 seconds, whereas the time limit for the difficult level was 1 minute.

Students' orthography skills were assessed applying a writing-to-dictation task. To this end, they were asked to fill in a dictated target word (i.e., blows) in 28 gapped sentences (e.g., 'The wind ________ fiercely.'). The target words selected for this task covered all central aspects of German orthography (e.g., capitalization of initial letter, consonant geminations, and lengthening signs).

4) Analysis

Due to differences in the assessment procedure (i.e., speeded tests for arithmetic and power tests for orthography), data analysis was conducted separately for the two competencies.

For analyzing the effects of the arithmetic training, responses given within the time limit were coded as either correct or incorrect for all types of problems (i.e., easy and difficult addition, subtraction, multiplication, division). Missing answers were coded as incorrect. All 150 items were considered in the analysis. To consider the impact of training type (i.e., arithmetic or orthography) as well as problem type (i.e., easy or difficult operations), linear mixed models (LMM) with a random intercept for children were used.

For quantifying the effect of the orthography training, students' spellings in the orthography test were coded as either correct or incorrect. All variations of misspellings were collected and linked to the individual child. For analyzing the data, item response theory models (IRT) were used. IRT models offer the possibility to separate item characteristics such as item difficulty from characteristics of the person (e.g., their ability). In the subsequent analyses, the Linear Logistic Test Model (LLTM, cf. [34]) was used to quantify the training effect as well as performance changes over time. As items presented at several test points were thought to change in difficulty over time, they were considered as "structurally" different. LLTM also offers the possibility to separate item difficulty changes between test points into a training effect and a general temporal trend.

For all analyses, the open source statistic software R was used (R Core Team, 2014). Linear mixed effect analyses and p-values for mixed models were calculated with the packages lme4 [35] and lmerTest [36]. The eRm package [37] was used to run conditional maximum-likelihood estimations of the parameters of the Linear Logistic Test Model. A criterion of α =.05 was applied to determine statistical significance.

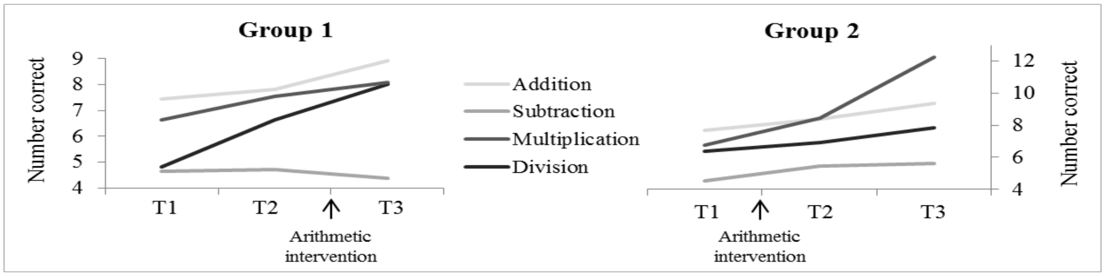

Fig.2: Mean arithmetic performance (easy tasks only) for group 1 (Arithmetic training: T2-T3) and group 2 (Arithmetic training: T1-T2) at the three test time points.

A. Results

1) Arithmetic

Regarding arithmetic, analyses revealed a significant main effect of problem type ($F_{7,\ 367.98} = 6.51$, $p < .001$). However, type of training as well as the interaction of both factors turned out to be non-significant ($F_{1,\ 367.98} = 0.54$, $p = .462$ and $F_{7,\ 367.98} = 0.88$, $p = .524$) indicating no specific effect of the arithmetic training.

With respect to the significant main effect of problem type, reliable performance improvements were only found for easy tasks such as easy addition (Least square means (LSM) ± SE = 0.791 ± 0.31, Confidence Interval (CI) = 0.182-1.401, p = .011), easy multiplication (LSM ± SE = 2.208 ± 0.31, CI = 1.599-1.338, p = .019) as well as easy division (LSM ± SE = 0.729 ± 0.31, CI = 0.120-2.817, p < .001). For the case of easy subtraction, no significant performance improvements were found.

Fig. 2 summarizes these results for easy tasks and depicts the average number of correctly solved problems in the arithmetic tests on the easy level over the three time points for both learning groups. From the figure it becomes clear that students improved their performance in easy addition, multiplication and division irrespective of the type of training (i.e., arithmetic or orthography), indicating a general rather than a specific training effect.

2) Orthography

To analyze the effect of the orthography training, the LLTM was fit to the data considering test points (3 time points), training groups (2 groups) and response format (0: spelling incorrect, 1: spelling correct) . All children solved at least one item correctly at T1 and only one child solved all items correctly in T3, indicating no evidence for floor or ceiling effects.

The estimated coefficient for the effect of the training was significantly different from zero (Effect of intervention: Estimate ± SE = 0.651 ± 0.28, CI = 0.100-1.202; Temporal trend T1 to T2: Estimate ± SE = 0.302 ± 0.21, CI = -0.111-0.716; Temporal trend T2 to T3: Estimate ± SE = -0.133 ± 0.21, CI = -0.554-0.287). This indicates that students improved their spelling performance significantly due to the orthography training.

Fig. 3A depicts the learning curves for both groups compared with a fictional learning curve representing the temporal trend (see dashed line). The curves of the intervention groups show an overall increase in children’s spelling ability, except for a decline in the ability parameter from T2 to T3 in group 1 (i.e., orthography training between T1 and T2, see black line). Fig. 3B shows that - at the group level - the mean model predictions of expected correct responses estimated with the LLTM were very close to the observed mean number of correctly written words.

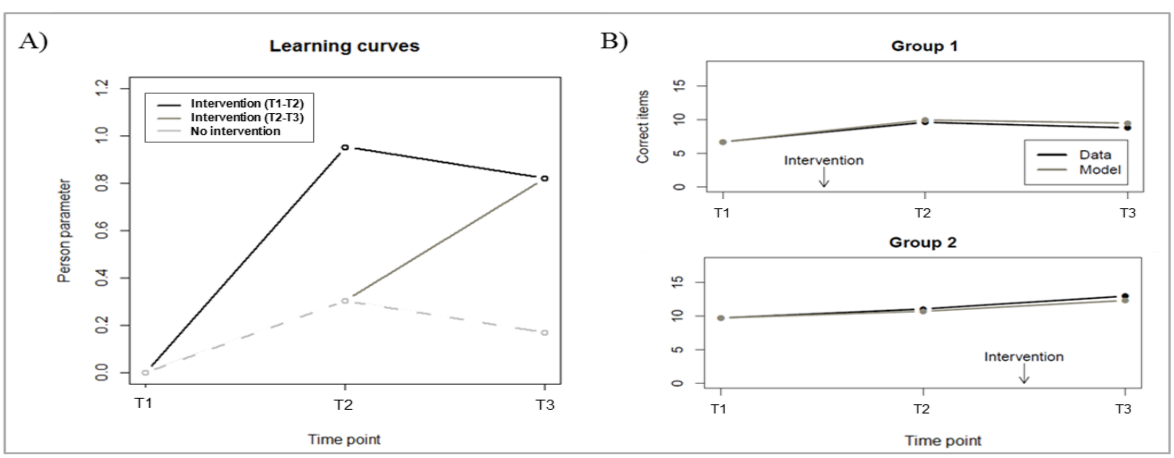

Fig. 3: A) Learning curves based on LLTM estimation; dashed line depicts the temporal trend of a fictive no-treatment group (T1-T2-Estimate: 0.302, T2-T3-Estimate: -0.133). B) Predicted and observed mean item responses.

A. Discussion

The aim of Study 1 was to evaluate in a pilot examination, whether 5th and 6th graders improve their arithmetic and orthography performance successfully by playing learning games hosted on our web-based learning platform.

The results regarding the numerical training showed that students significantly improved their performance throughout the study – although not specifically through the arithmetic but also the orthography training. This general improvement was, moreover, only found for easy addition, multiplication and division, but neither for more difficult operations nor for subtraction. Two possible explanations for the absence of a specific numerical training effect might be considered.

First, the arithmetic games might not have addressed specific mathematical abilities in the respective age group, but rather general abilities like attention, concentration or working memory. This seems unlikely, as similar interventions have led to specific improvements in the past (e.g., [38] - [40]). Additionally, the general performance improvements observed in the present study were at least specific with respect to the skills trained by the three arithmetic games (‘Multiplication’, ‘Partner Number’, and ‘Carry Game’). These games aimed at training easy additions and multiplications, but also included – at least indirectly – a training of divisions as students were requested to match a given result (e.g., 18) to the corresponding components of the problem (e.g., 3 x 6; for the mediation between multiplication and division see [28], [41], [42]). More difficult operations or subtraction skills, for which no intervention effects were observed, were neither trained nor improved.

Another explanation for the lack of a specific intervention effect might be that the arithmetic games indeed trained specific numerical skills, although not sufficiently effective to outperform the impact of the orthography training which might have improved some (unspecific) abilities related to arithmetic (e.g., sequential, symbolic, and spatial processing, but also attentional as well as working memory processes). In support of this explanation, the observed training effects match the content of the learning games, but did not differ significantly from the effects the orthography training had on students’ numerical skills. In line with previous findings indicating that numerical trainings are most effective when targeted at basic numerical skills ([43]; for a meta-analysis see also [44]), the learning games were designed to train students’ numerical skills at a low level of difficulty. However, this level might have been too low for the majority of students although possibly suitable for less skilled or dyscalculic children. A reason for the arithmetic training being less effective than expected may, thus, be that the learning games were too easy so that at least some students could not improve their skills sufficiently.

Additionally, an inadequate matching of game partner might have reduced some students’ motivation to play (cf. [23]), which could have affected their learning progress. Therefore, we aim at further improving the learning platform by implementing an adaptive assessment prior to playing the games. This assessment should allow for an individual, automated and computer-based matching of game partners. The adequacy of the difficulty level and possible modifications on the difficulty of the numerical learning games will be discussed below considering the results of the survey among teachers (see Study 2).

In contrast to arithmetic, the results of the orthography training on the learning platform (i.e., ‘Gemination Game’, ‘Word Families’, and ‘Word Building Blocks’) turned out to be more conclusive. A specific intervention effect was found indicating that students improved their overall spelling performance significantly due to orthography training. In line with previous findings this result shows that children’s spelling skills might be enhanced by a training of phonological awareness and morphological consistency (cf. [31], [32]). Furthermore, it indicates that computer-supported learning games are applicable to corroborate children’s spelling skills and orthographical knowledge. With respect to the method used to analyze the data (i.e., LLTM) it should be mentioned that, in fact, larger samples would be desirable to obtain more robust parameter estimates with better statistical power. Although the size of the present sample was rather small, the results turned out to be significant indicating a robust and fairly large specific training effect for the orthography training.

Last but not least, this first rollout to the field was also targeted at informally testing the technical and organizational conditions of schools as well as the overall acceptance of the learning platform. In the present study, the involved schools did not fulfill the technical requirements to integrate the platform into classes. Computer labs could not be used due to low bandwidth and server problems. Thus, a mobile classroom comprised of laptops connected pair-wisely had to be installed. This made it possible to play the games via connection to local servers but did not allow for access to the online platform. As a matter of fact, this can only be a temporary solution to the infrastructural problems. A possible solution for future versions of the platform might be to consider server-push-based communication models with a central server that initiates the request for the upcoming transaction [45]. Furthermore, we observed that some students had problems with understanding the instruction of the learning games and needed the experimenter’s help to start. A practice phase prior to each game might solve this issue and ensure that students understand and enjoy playing from the very beginning.

To supplement the insights gained from this pilot evaluation of the platform by the perspective of those who may wish to use the platform for educational purposes, the following section will report the results of a survey among teachers. This survey will not only provide an informative basis on which learning topics are regarded most relevant and difficult in 5th and 6th grade. Furthermore, it might offer valuable suggestions to account for the different training effects in arithmetic and orthography and might thus contribute to further advancing the learning platform.

II. Study 2: A survey among teachers

Study 2 investigated (i) the difficulty and relevance of several learning topics in the domains of arithmetic and orthography in the 5th and 6th grade as well as (ii) the use and acceptance of computer-supported teaching methods in schools. To pursue this aim, we designed an online questionnaire and asked German secondary school teachers in the area of Baden-Württemberg to participate in the survey. The questionnaire comprised two parts: (Part I) difficulty and relevance of learning topics and (Part II) use and acceptance of computer-supported teaching methods. Teachers answered both parts either for arithmetic or for orthography.

Domain	Superordinate learning topics	Subordinate learning topics	
Arithmetic	1. Numbers/Place-value system	▪ One-digit numbers ▪ Two-digit numbers ▪ Three- and multi-digit numbers	▪ Negative numbers ▪ Decimals
	2. Calculation rules	▪ Multiplications/divisions solved before additions/subtractions ▪ Commutative law	▪ Associative law ▪ Distributive law
	3. Rounding	▪ Rounding numbers	
	4. Measurement units	▪ Transforming measurement units (e.g., l to ml) ▪ Scales (e.g., 1:1000)	
	5. Additions	▪ One-digit numbers ▪ Two-digit numbers ▪ Three- and multi-digit numbers	▪ Carry-over problems ▪ Adding in written form
	6. Subtractions	▪ One-digit numbers ▪ Two-digit numbers ▪ Three- and multi-digit numbers	▪ Borrow problems ▪ Subtracting in written form
	7. Multiplications	▪ One-digit numbers ▪ Two-digit numbers ▪ Three- and multi-digit	▪ Potencies ▪ Multiplying in written form
	8. Divisions	▪ One-digit numbers ▪ Two-digit numbers ▪ Three- and multi-digit	▪ Roots ▪ Dividing in written form
	9. Fractions	▪ Understanding fractions ▪ Expanding and reducing ▪ Adding and subtracting	▪ Multiplying and dividing ▪ Comparing
	10. Word problems and diagrams	▪ Transforming measurement units (e.g., l to ml) ▪ Scales (e.g., 1:1000)	
	11. Geometry	▪ Distances ▪ Areas ▪ Geometrical bodies (e.g., cone)	▪ Circles ▪ Angels ▪ Symmetries
Orthography	1. Spelling strategies and techniques	▪ Looking up ▪ Proof of article ▪ Word families ▪ Prolonging words	▪ Syllabification ▪ Correcting mistakes in own texts ▪ Use of spelling programs
	2. Spelling rules - Upper and lower case	▪ Word classes ▪ Nominalization ▪ Articles	▪ Polite speech
	3. Spelling rules - Long vowels	▪ "h" after long vowels ▪ Double vowels ▪ Word with "ie", "ih", and "ieh"	▪ Exceptions ▪ Homophones ▪ Loanwords
	4. Spelling rules - Consonant germination	▪ Identifying short vowels ▪ Geminations ▪ Word with "ck"	▪ Words with "tz" ▪ Loanwords
	5. Spelling rules - Similar phonemes	▪ Similar vowels, diphthongs and German "Umlaute"	▪ Final-obstruent devoicing (e.g., g/k, d/t, b/p)

Table I: Summary of learning topics covered in the questionnaire.

A. Method

1) Participants

In total, 184 secondary school teachers participated in the survey. 56 teachers had to be excluded due to missing data (dropout rate 30%), resulting in complete datasets for 128 participants. About half of the teachers answered the questionnaire with respect to 5th graders (53%), whereas the other half referred back to 6th graders. Regarding years of teaching experience, participants covered a wide range from job starters (1 year) to highly experienced professionals (42 years; M = 16; SD = 13).

Overall, 67 teachers answered part I of the questionnaire for orthography and 61 for arithmetic. 59 and 56, respectively, of these respondents also completed part II comprising questions on computer-supported teaching methods.

2) Materials and Procedure

Part I of the survey comprised eight questions that had to be answered with respect to several specified learning topics regarding either arithmetic (e.g., rounding, addition) or orthography (e.g., spelling rules). Three questions that addressed the students' acquisition of these topics are of particular interest for this paper and will be focused on in the following results section. (1) How many children have too little prerequisites for mastering this learning topic? (2) How difficult to master is the learning topic for students? (3) How relevant is the learning topic for the students' further development in the subject? The other questions primarily dealt with the learning topics themselves (e.g., "Is this topic explicitly taught in this grade?" or "How much time is spent on this topic in this grade?").

As depicted in Table 1, teachers responded to all questions with respect to 11 superordinate learning topics regarding arithmetic (covering 46 subordinate learning topics) and 5 superordinate topics concerning orthography (covering 24 subordinate learning topics).

Part II of the survey comprised 9 questions and aimed at assessing the teachers' use and acceptance of computer-supported teaching methods for arithmetic and orthography. Four questions were designed in open format to cover the whole range of response options and give room for individual statements (e.g., "For which learning topics do you use the computer with your students?" or "For which learning topics would a web-based learning platform be helpful and relevant?"). Five questions were designed in closed format with specified response options. To reduce complexity, only these five questions will be presented and discussed in the result section: (1) How often do you use computer-supported teaching methods in your lessons? (2) Do you use digital learning games in your lessons? (3) Would you use a web-based learning platform in your lessons? (4) Would it organizationally and technically be possible to use a web-based learning platform in your school? (5) Which characteristics should a learning platform fulfill to be attractive and motivating for your students?

B. Results

In the following paragraphs we will first present the results of part I of the questionnaire (i.e., difficulty and relevance of learning topics) – separately for arithmetic and orthography – and will then describe the results for part II (i.e., use and acceptance of computer-supported teaching methods).

1) Part I: Arithmetic

All questions were answered by selecting a specified category. To summarize responses, we will report for each learning topic the category which was chosen by most teachers.

Question 1: How many children have too little prerequisites for mastering this learning topic?

Teachers gave their answer by selecting one out of three specified categories (i.e., at least 30% of the students, at least 50% of the students, almost none).

Most teachers (42%) indicated that at least 50% of their students have too little previous knowledge from former grade levels to handle measurement units appropriately. Furthermore, most respondents indexed that at least 30% of the students would not fulfill the necessary requirements to successfully apply calculation rules (43%) and rounding (52%), to master geometry (36%) or to calculate more complex multiplications (35%), divisions (30%) and word problems/diagrams (57%). Almost none of the students, as estimated by teachers, were thought to lack in previous knowledge regarding numbers and the place-value system (37%), additions (53%) or subtractions (42%). Note however, that this was also true for one- and two-digit multiplications (62% and 43%) as well as division with one-digit divisors (54%). Concerning the learning topic of fractions, most teachers (39%) did not specify their answer, probably because this theme is not covered before 6th grade.

Question 2: How difficult to master is the learning topic for students?

Teachers gave their answer by selecting one out of three categories (i.e., easy, moderate, difficult).

Most teachers agreed that numbers and the place-value system as well as additions are in general easy to master for 5th and 6th graders (35% and 50%, respectively). Exceptions to this were decimals, carry-over additions and adding in written form. These subordinate topics were mostly thought to be moderate in difficulty (by 43%, 50%, and 51% of teachers, respectively).

Moderate difficulty was also ascribed to the following superordinate learning topics: calculation rules (50%), rounding (59%), subtraction (42%), multiplication (44%), word problems/diagrams (54%), and geometry (39%). Note however some exception on the subordinate level: subtracting one- (66%) and two-digit numbers (44%), both part of the superordinate topic subtraction, as well as multiplying one-digit numbers (59%), assigned to the superordinate topic multiplication, were estimated to be rather easy. Applying the distributive calculation rule (36%) – a subordinate topic of calculation rules – as well as solving word problems (48%) – superordinate topic word problems and diagrams – were instead thought to be difficult.

Handling measurement units and solving divisions were estimated to be difficult by most teachers (59% and 38%, respectively), except for one- and two-digit divisions, which were estimated to be moderate in difficulty (46% and 41%, respectively).

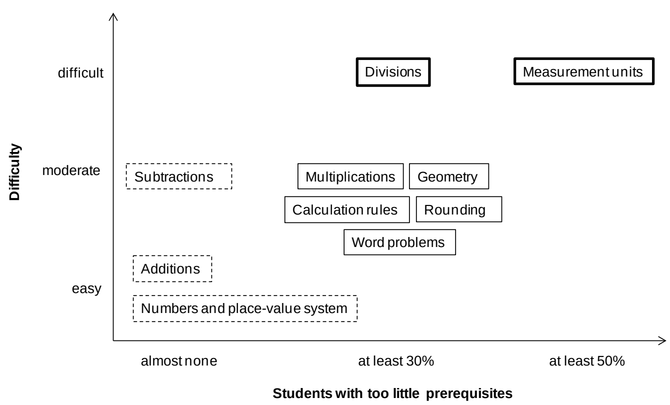

Fig. 4: Visualization regarding the difficulty of learning topics in the field of arithmetic (question 1) and the prerequisites of students in these topics (question 2) as estimated by teachers. Dashed and bold lines indicate that teachers selected an extreme category in response to least one question.

Fig. 4 summarizes the results of questions 1 and 2. It clearly depicts that additions, subtractions as well as numbers and the place-value system seem to be those learning topics that have the lowest need for extra training. Almost all secondary school children appear to have the necessary prerequisites to master these topics and teachers estimated these themes to be rather easy. In turn, divisions and measurement units turned out to be especially difficult topics (except for one- and two-digit divisions). These seem to require special support as at least 30% to 50% of students were indicated to not have sufficient prior knowledge to succeed.

Question 3: How relevant is the learning topic for the students' further development in arithmetic?

Teachers gave their answers to this question by selecting between three categories (i.e., hardly, moderately and highly relevant).

Analyses showed that most teachers (39% to 75%) estimated all superordinate learning topics to be highly relevant for students' further progress in the subject. Interestingly, they also agreed largely in their opinion as percentages exceeded 50% in almost all cases. Only two subordinate learning topics were thought to be of only moderate relevance: symmetries (34%) and scales (34%).

2) Part I: Orthography

The same questions as for the arithmetic part of the survey were asked with respect to orthography. Thus, we will analyze and summarize teachers' responses in the same way.

Question 1: How many children have too little prerequisites for mastering this learning topic?

Teachers gave their answers to this question by selecting one out of three categories (i.e., at least 30% of students, at least 50% of students, almost none).

For all learning topics, most teachers were of the opinion that at least 30% of their students have too little prerequisites for mastering the topic successfully: spelling strategies and techniques (43%), upper and lower case (38%), spelling of long vowels (42%), consonant germination (49%), and similar phonemes (52%). Only one exception to this was found: Regarding nominalization, a subordinate topic of upper and lower case, most teachers (37%) indicated that even more than 50% of their students would not fulfill the necessary prerequisites.

Question 2: How difficult to master is the learning topic for students?

Answers to this question were given by selecting one out of three categories (i.e., easy, moderate, difficult).

The majority of teachers estimated all learning topics to be of moderate difficulty: spelling strategies and techniques (42%), similar phonemes (54%), upper and lower case (42%), spelling of long vowels (46%), and consonant germination (47%). However on the subordinate level, identifying word classes was thought to be rather difficult (61%), whereas spelling homophones (40%) as well as long vowels and consonant germinations in loanwords (46% and 42%) was estimated to be easy.

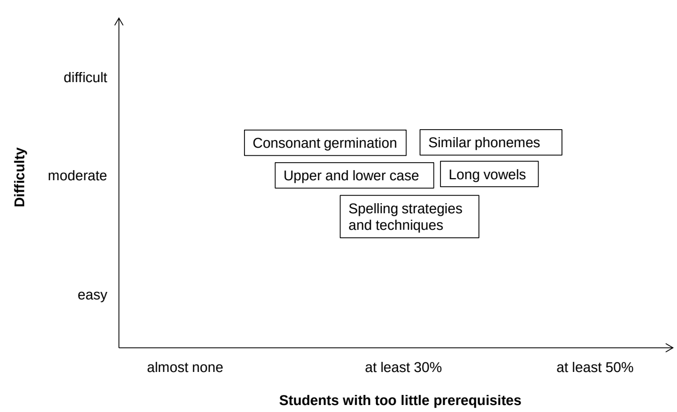

Fig. 5: Visualization regarding the difficulty of learning topics (question 1) and the prerequisites of students in these topics (question 2) with respect to orthography as estimated by teachers.

Summarizing these results, Fig. 5 visualizes the difficulty of the learning topics as well as students' prerequisites for these topics as indicated by the participating teachers. Form this it can be read that all learning topics were estimated to be moderately difficult, whereas at least 30% of students' were thought to lack in prior knowledge. These results suggest that students would probably profit from further support in most learning topics regarding orthography.

Question 3: How relevant is the learning topic for the students' further development in orthography?

Teachers gave their answers to this question by selecting between three categories (i.e., hardly, moderately and highly relevant).

Similar to the arithmetic part of the questionnaire, all learning topics were estimated to be highly relevant for students' further development in the subject: spelling strategies and techniques (66%), upper and lower case (60%), spelling of long vowels (49%), consonant germination (56%), and similar phonemes (62%). However on the subordinate level, four learning topics were estimated to be of only moderate relevance: The use of spelling programs as spelling aid (40%), the use of articles to detect capitalizations (69%), and spelling long vowels and consonant germinations in loanwords (40% and 40%). Again, teachers agreed largely on this question as percentages exceeded 50% for almost all superordinate learning topics.

3) Part II: Computer-supported teaching methods

Question 1: How often do you use computer-supported teaching methods in your lessons?

Answers to this question were given by selecting one out of four response options (i.e., not used, more than once in 6 months, once a month, more often). In general, more than half of the teachers (58%) reported to use computer-supported teaching methods. 38% stated to use them more than once in 6 months, whereas only 14% reported to make use of them once a month or even more often (6%). However, 37% of teachers also stated that they never use this kind of teaching method.

Interestingly, a difference between orthography and arithmetic teaching became obvious. While 69% of teachers reported to use computer-supported teaching methods in their orthography lessons (44% reported to use them more than once in 6 months, 20% once a months, 5% more often), only 46% stated to use these methods for arithmetic (32% more than once in 6 months, 7% once a months, 7% more often). In turn, 47% stated to never use computer-based methods in their arithmetic lessons, whereas only 27% reported this for orthography (7% and 4%, respectively, did not specified their response). This indicates that computer-supported teaching methods are in general more present in orthography than in arithmetic instruction.

Question 2: Do you use digital learning games in your lessons?

Teachers gave their answers by choosing one out of three response options (i.e., computer-based games, web-based games, other games, no digital learning games).

Only 14% of teachers stated to integrate computer-based games, web-based games (10%) or other digital games (9%) in their lessons. However, more than half of the teachers reported to use no digital learning games at all (61%). Furthermore, almost no difference became apparent between arithmetic and orthography teaching. While 63% reported to use no digital learning games in orthography, 59% stated this for arithmetic.

These results contradict those of question 1 at first sight, but may point to the fact that those computer-based learning methods integrated by 58% of the teachers into their lessons (see question 1) mainly comprise text production programs to create own texts (e.g., essays, emails or formal letters), whereas the use of game-based digital learning seems to be rather scarce at school.

Question 3: Would you use a web-based learning platform in your lessons?

More than half of the teachers (57%) stated that they would integrate a web-based learning platform into their lessons. 33% declared that they would probably not use such a web-based learning method and 10% did not specify their answer. Again, teachers were a little more open to use a web-based learning platform for orthography (61%) than for their arithmetic lessons (54%).

Question 4: Would it organizationally and technically be possible to use a web-based learning platform in your school?

Regarding technical and organizational facilities, 42% of teachers stated that their schools would fulfill the necessary requirements. However, about as many teachers claimed their schools would not (47%), whereas 11% did not specify their answer. This ambiguity might point to considerable differences between schools regarding the technical and organizational facilities required to integrate web-based learning games in school education.

Question 5: Which characteristics should a learning platform fulfill to be attractive and motivating for your students?

Teachers gave their answers by choosing one out of three response options (i.e., designed as game/competition, computer-based/web-based, designed to play in pairs/groups).

Most teachers (55%) indicated that a learning platform should be designed as a game or competition to be most attractive for students. Moreover, 33% highlighted that such a platform should be computer-based or web-based and should be designed to play in pairs or groups (34%).

C. Discussion

The aim of study 2 was to evaluate the difficulty and relevance of several learning topics in the domains of arithmetic and orthography as well as to specify the use and acceptance of computer-supported teaching methods at school. For this purpose we specifically developed a questionnaire for secondary school teachers.

The results showed a clear difference between arithmetic and orthography regarding the estimated difficulty of learning topics. In the field of orthography, all learning topics were thought to be moderately difficult for students while at least 30% of the students were assumed to lack in previous knowledge necessary to master the topic successfully (for similar results based on a standardized German orthography test see [46]). However, with respect to arithmetic, some learning topics were thought to be rather easy with most students fulfilling the necessary prerequisites for succeeding (i.e., additions, subtractions and numbers/place-value system), whereas other learning topics were indicated to be rather difficult (i.e., divisions and measurement units) with at least 30% to 50% of students lacking in previous knowledge (for similar results see also [27]). This shows that most students would probably profit from additional support in a rather wide range of orthographic rules and strategies. In contrast, however, specific extra training in addition, subtraction and numbers/place-value system seems to be helpful for a smaller number of students only.

Regarding the relevance of the learning topics for students' further progress in the subject, teachers indicated all superordinate topics in orthography as well as in arithmetic to be highly relevant. Furthermore, they substantially agreed on their appraisal as ratings exceeded 50% in almost all cases. This consensus is reasonable as most learning topics in arithmetic (and also some in orthography) built on one another. Furthermore, these results might also point to the fact that teachers tend to consider all learning topics in their subject to be highly relevant, whereas 'non-experts' would probably not attribute that much significance to certain topics.

With respect to the use of computer-supported teaching methods, the results revealed that the majority of teachers already integrate computer-supported learning into their lessons as it is required in the curriculum (cf. [47]). However, most of them do so rather infrequently (i.e., less than once per month; for similar results see also [48], [49]). A closer look at the data revealed that computer-based teaching methods were reported to be used more often for orthography than for arithmetic. This discrepancy might point to the common use of text production programs (cf. [50]) which are used in orthography but not arithmetic lessons. This is also well in line with the fact that game-based digital learning is rather scarce in both subjects, although computer-supported teaching methods in general are used at least occasionally.

Despite their scarce use of game-based digital learning, most teachers stated, however, that a web-based learning platform should be designed as a competitive learning game to be most attractive and motivating for students. Furthermore, most of them claimed to be willing to integrate such a platform into their lessons, indicating a demand for playful and motivating learning games for secondary school children. However, almost 50% of the interviewed teachers also mentioned that they would probably face difficulties when using a web-based learning platform in their lessons (e.g., unstable internet connection, insufficiently equipped computer labs, out-of-date hardware, no Wi-Fi in the classroom, etc.).

Taken together, the results of the present survey were informative and insightful. They revealed need for extra training in several learning topics, and disclosed teachers use of computer-supported teaching methods in general and of a web-based learning platform in particular. Nonetheless, these results should be considered with caution, because of the limited number or participating teachers. Therefore, future studies would be desirable substantiating and extending these results.

III. General Discussion and Conclusions

In the present project, a web-based and socially-interactive learning platform for arithmetic and orthography was designed, implemented and evaluated. The pilot evaluation of the learning platform (Study 1) revealed promising results. While the arithmetic training only led to general intervention effects, the orthography training specifically enhanced 5th and 6th graders spelling performance. These results are in line with previous findings indicating that computer-supported interventions are suitable to corroborate numeracy and literacy [51], [52]. However, the arithmetic training turned out to be less effective than expected. A reason for this might be that the operations trained (i.e., one-digit addition and multiplications as well as indirectly also divisions) may have been too easy for the majority of students although possibly suitable for less skilled or dyscalculic children. This account is further supported by the results of the survey among teachers (Study 2). Study 2 revealed that one-, two-, and multi-digit additions as well as one-digit multiplications are rather easy learning topics as estimated by teachers. Furthermore, most teachers indicated that almost all of their 5th and 6th graders would fulfill the necessary prerequisites for mastering these topics. This suggests that simple additions and multiplications seem to be those learning topics that have the lowest need for extra training – at least as estimated by teachers.

However, the absence of a specific training effect for arithmetic might also be due to an inadequate matching of game partners which may have led to reduced motivation to play in those students who were primarily defeated by their opponents (cf. [23]). Future versions of the learning platform should thus consider different levels of difficulty as well as an adaptive and computer-based assessment to automatically match opponents according to their skills.

Another aim of the pilot evaluation was to informally test in a first roll-out to the field whether schools would fulfill the technical and organizational requirements to integrate a web-based learning platform into classes. At least the two schools involved in our study turned out to be insufficiently equipped which required the installation of a mobile classroom for the pilot evaluation (i.e., pair-wisely connected laptops; one serving as client, the other hosting the learning platform). This experience is in line with the results of the survey. Almost 50% of the interviewed teachers mentioned that they would probably face difficulties such as unstable internet connections when using a web-based learning platform in their lessons. Thus, a challenge for improving the learning platform in the future will be to reduce its technical requirements as much as possible to compensate insufficient technical infrastructure at some schools.

Taken together, the present project gained both insightful and promising results indicating that computer-supported learning environments may be suitable to corroborate numeracy and literacy skills in formal education. Furthermore, we gained important indications on how to further improve our web-based learning platform. Thus, future versions will, for instance, include different levels of difficulty as well as an adaptive, initial assessment to match opponents according to their skill level. Moreover, we aim at reducing the technical requirements such as upload capacity to take account for insufficient technical infrastructure at some school. By implementing these modifications, the web-based learning platform will be further improved, offering the possibility to complement formal learning setting by digital learning games - accessible anywhere and anytime.

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