International Journal of Child-Computer Interaction 44 (2025) 100740

Contents lists available at ScienceDirect

International Journal of Child-Computer Interaction

journal homepage: www.elsevier.com/locate/ijcci

Research Paper

Adaptive metacognitive prompting in young learners and the role of prior performance

Rebecca Pape *, Joachim Thomas

Department of Psychological Assessment and Intervention, Catholic University of Eichstätt-Ingolstadt, Germany

A R T I C L E I N F O

Keywords:
Self-regulated learning
Metacognitive prompting
Online behavior
Adaptivity
Secondary education

A B S T R A C T

Metacognitive prompting has been shown to effectively support Self-Regulated Learning (SRL) in computer-based learning environments (CBLEs) and thereby enhance learning performance. Adaptive prompting as a way to successfully tailor prompts to the learners' needs remains understudied, especially among young learners in lower secondary education who were shown to be in a critical phase in their development of metacognitive skills. The present study investigates the effects of adaptive, metacognitive prompting on SRL activities through self-reports and trace data, and on learning performance. In a pre-post experimental design, 72 lower secondary students received prompting ($n = 38$) or no prompting ($n = 34$). Results show that metacognitive prompting led to higher self-reported metacognitive SRL activities. It did not result in significant differences in learning performance, however, prior performance level was identified as a significant moderator. Implications for SRL research with focus on low achieving learners are discussed.

1. Introduction

Learning in computer-based learning environments has attracted increasing interest from policymakers, educators, and researchers following the COVID-19 pandemic and the increasing availability of modern technologies in the educational sector. In these online environments, students are given more autonomy to create their own learning processes, yet, require them to better self-regulate their learning (SRL; Hew et al., 2023). SRL refers to consecutive, cyclical activities in which learners adjust their thoughts, feelings, and actions to attain their individual goals (Zimmerman, 2000). Previous findings in SRL research indicate that learners' SRL activities can be improved through interventions (Ceron et al., 2021; Lee et al., 2019; Wong et al., 2019; Yen et al., 2018).

Various interventions aimed at assisting learners in their SRL have demonstrated positive effects on learning performance and related learning measures. Findings suggest that SRL support can positively influence educational performance (Espinoza & Genna, 2021; Xu et al., 2023), mitigate undesirable learning patterns (Lodge et al., 2018), augment students' mastery goals (J. Zheng et al., 2020), and emphasize its impact on enhancing self-efficacy (Samuel & Warner, 2021). Moreover, Putwain and von der Embse (2020) discovered that these interventions were effective in reducing students' test anxiety. Nevertheless, it remains evident that numerous sub-processes of SRL necessitate distinct types of SRL support, appropriately timed within the educational process, and adapted to the learners' needs (Heikkinen et al., 2023). In particular, SRL support aimed at supporting younger learners in lower secondary school in computer-based learning environments (CBLEs) remains understudied.

The present research, therefore, investigates whether adaptive metacognitive prompting is an adequate tool for younger learners in lower secondary school to support their metacognitive SRL activities as well as their learning performance. The design process of the adaptive metacognitive prompts is presented in detail with the learner-centered approach including the students in lower secondary school. Process measures and product measures that were used to evaluate the influence of the adaptive metacognitive prompts are described in the following.

2. SRL support and learner characteristics

Scaffolding as a way to support SRL has been investigated from various perspectives including its effects on recall and transfer knowledge (Bannert et al., 2015; Sonnenberg & Bannert, 2016, 2019), on group activities and group performance (Molenaar et al., 2011), in educational settings (Azevedo et al., 2004; Bannert, 2007, 2009; Sonnenberg & Bannert, 2016) and in workplaces (Siadaty et al., 2016a;

* Corresponding author. Department for Psychological Assessment and Intervention, Ostenstraße 25, 85072 Eichstätt, Germany.
E-mail addresses: Rebecca.pape@stud.ku.de (R. Pape), Joachim.thomas@ku.de (J. Thomas).

https://doi.org/10.1016/j.ijcci.2025.100740
Received 22 August 2024; Received in revised form 17 April 2025; Accepted 1 May 2025
Available online 2 May 2025
2212-8689/

Siadaty et al., 2016b). However, recent research has called for a focus on person-centered rather than variable-centered approaches in SRL research (e.g. Chen et al., 2023; Dörrenbächer & Perels, 2016), as findings of studies indicate that, next to design variations and the choice of SRL subprocesses, human factors moderate the effects of SRL support on SRL processes and learning performance (Pieger & Bannert, 2018; Wong et al., 2019).

Few studies have investigated how learners' individual differences influence the effectiveness of SRL support. Prior studies reveal that achievement goal orientation (Duffy & Azevedo, 2015), achievement level (Manlove et al., 2007), level of metacognition (Zhang et al., 2015), level of prior knowledge (Yeh et al., 2010), or cognitive ability (Sitzmann et al., 2009) appear to moderate the positive effects of SRL support.

Concerning SRL abilities, Dörrenbächer and Perels (2016b) found that those with moderate and motivated SRL profiles benefited most from the SRL support, while those with low and high SRL profiles did not. Concerning prior knowledge, high levels were found to positively influence both the use of SRL support (Azevedo et al., 2022; Taub et al., 2014) and thereby impact learning performance (Bannert & Reimann, 2012; Bouchet et al., 2018; Kramarski et al., 2013). Taub et al. (2014) found differences between high and low prior knowledge groups in metacognitive SRL strategies, but not in cognitive SRL strategies, suggesting that prior knowledge is particularly relevant to metacognitive SRL. Kramarski et al. (2013) examined the effects of generic versus context-specific SRL support approaches and concluded that 7th-grade students with high prior knowledge benefited less from the support than the low prior knowledge group. Concerning ability in terms of academic achievement, van Dijk et al. (2016) found that high-ability children used the prompts when presented, compared to moderate or low-ability children who rarely utilized the prompts. This finding has also been reported by other studies, such as Munshi et al. (2023) who found that high and low outcome achievers responded differently to hints and displayed different learning behavior.

These studies implicate that, in contrast to other studies, it is not only the features of the prompts that need to be considered when designing SRL support. Also, the learners' characteristics play a vital role indicating that certain treatments may be beneficial for different individuals (Pieger & Bannert, 2018; Snow, 1991). More rigorous investigations are needed to adapt SRL support to the learners' individual needs, balancing their individual learning prerequisites with the required learning standards.

3. Adaptive SRL support

Recent research has proposed technological solutions that adapt instructional methods to the learner's level of expertise and create adaptive training (Wong et al., 2019). Positive impacts of incorporating adaptability and individualization into CBLEs have been observedKlicken oder tippen Sie hier, um Text einzugeben., however, when comparing adaptive scaffolds with no or fixed scaffolds, mixed results have been found regarding their effectiveness (Li et al., 2023; Munshi et al., 2023). A key factor that influences the effectiveness of the adaptive prompts is the in-situ data on the learners' current level of knowledge, recently proposed as the foundation of effective scaffolding (Järvelä et al., 2019).

As learning needs change during the learning process, a valuable method for discovering learning processes as they occur and linking those processes to learning performance has shown to be learning analytics (Heikkinen et al., 2023; Lodge et al., 2018; Winne, 2022). By means of learning analytics models built on the four stages of data generation, tracking, analysis, and action (Heikkinen et al., 2023; Romero & Ventura, 2020), researchers and practitioners can identify learning behaviors that require intervention and define them as trigger points to provide support. However, identifying the right data as triggers for support remains a challenge.

Several studies have tested the use of different triggers to adapt their support to the needs of the students. Examples of using learning progress in a task or a sequence of tasks as a trigger for support can be found in intelligent tutoring systems (ITS) such as *Crystal Islands* (Spires et al., 2011), which implemented a tracking method to measure tasks completed and then add quizzes at certain points. Also, the learning environment *MetaTutor* (Azevedo et al., 2009) which collected data through multiple channels such as log files and eye tracking, triggered a pedagogical agent to prompt the students to engage in different learning strategies (Azevedo et al., 2022). The learning environment *Betty's Brain* incorporated analyzes of ongoing learning behavior to identify students' learning patterns and key transition points which then served as the basis for providing students with strategy scaffolds to help them develop knowledge within the learning environment (Biswas et al., 2016; Munshi et al., 2023) Finally, Molenaar and Roda's (2008) learning environment *AtgentSchool* provided 5th-grade students with adaptive scaffolds based on their activities in the e-learning application, learner characteristics and students' attention focus.

In understanding how adaptive SRL support can effectively enhance learners' SRL and their learning performance in CBLEs, several studies have investigated the optimal timing for scaffolding and how to tailor content to the learners' individual progress and needs. From these findings, it appears promising to combine accurate diagnosis of learners' learning processes with adaptive scaffolds that thereby align individual learning behaviors and learning needs with appropriate SRL support. To create appropriate SRL support for young learners in particular, more research is needed to explore their current and supported SRL activities.

4. Adaptive metacognitive prompting in young learners

Previous research has shown that metacognitive skills develop gradually over time (van der Stel & Veenman, 2010, 2014; Veenman & Beishuizen, 2004; Veenman & Spaans, 2005). The development of self-regulation was shown to begin in early childhood (Whitebread et al., 2007), with elementary forms of metacognitive skills found in preschool years (Whitebread et al., 2009). As a result of maturational and age-related changes such as a higher level of executive functioning (Diamond, 2016) and a shift from an emotional and external orientation to a more cognitive and internal orientation in their thinking (Montroy et al., 2016), these skills become more sophisticated during primary school. Primary school students are, furthermore, shown to have a growing (metacognitive) awareness regarding their thinking and controlling processes (Perry et al., 2017).

Throughout secondary school, these skills increase in quantity and quality (van der Stel & Veenman, 2014). Secondary school learners, however, frequently do not spontaneously regulate their learning, struggle to adequately plan, monitor, and evaluate their learning (production deficit, Flavell, 1979; Veenman et al., 2005), and thus, lack the skills of a self-regulated learner (Askell-Williams et al., 2012; Lawson et al., 2019; Vosniadou, 2020). However, the ability to self-regulate should not be seen as an "all-or-nothing phenomenon" (Schunk & Ertmer, 2000, p.632), but rather as an ability that can be learned depending on the developmental stage of the learner (Bronson, 2000). In the age of ten to twelve years old, in particular, metacognitive skills were found to be in a critical phase of development. Learners were found to start to apply metacognitive skills across domains, thus, developing the ability to generalize strategies that are used in specific domains to other domains (Veenman & Spaans, 2005).

Due to recent developments in technology and online learning, even young learners learn in CBLEs, and requires them to apply SRL skills also in these new learning environments (Broadbent & Poon, 2015). To address this challenge, prompting has been found to effectively support metacognitive SRL activities in CBLEs (Guo, 2022; L. Zheng, 2016). These prompts, as a type of scaffolding, can support learners in all cyclical phases of SRL (Bannert, 2009). In the forethought phase, learners can be prompted to analyze the task, set themselves goals, and strategically plan their learning process. In the performance phase, prompts can be aimed at supporting learners to employ strategies to monitor their learning process and to perform the task. In the final phase, the reflection phase, prompts can help learners evaluate their progress against a predefined goal and reflect on and adapt their actions for future learning (Panadero, 2017; Puustinen & Pulkkinen, 2001; Sonnenberg & Bannert, 2015).

Many studies analyzing the effects of adaptive metacognitive prompting in CBLEs have, however, mainly focused on university students (for an overview see Lim et al., 2022). Three of the very few studies that have explored the effects of prompting with young learners are presented here and the need for adaptivity is identified for each.

Hsu et al. (2017) developed cognitive and metacognitive prompts for 9th-grade students in a web-based learning environment and found that successful students engaged in metacognitive activities including monitoring and evaluating during the inquiry tasks while prompted at a significantly more frequent rate than the less successful students. Also, their engagement in metacognitive activities was found to be in distinct sequences. The prompts were, however, neither adaptive in terms of timing, nor was the content adapted to the students' needs. They concluded that crucial learning patterns of successful students were identified which can serve as a basis to design necessary support for less successful students. They called for scaffolds that are more dynamically responsive to individual learning patterns and needs.

van Dijk et al. (2016) conducted a study with 5th and 6th graders, investigating the effects of prompts on children's inquiry process and their learning outcomes. Their results showed that high-ability students demonstrated a more effective learning process than students with average and low ability. Also, they made use of the prompts more often than average and low-ability students who were found to use the prompts in a limited way. The authors conclude that, for young learners to effectively use the prompts, domain-specific prior knowledge may be a factor influencing the ability to better understand the content of the prompts. The language and the number of prompts were piloted prior to the study, however, no adaptability was included. Their findings hint at the necessity of creating adaptive scaffolds that are sensitive to varying levels of prior knowledge among young learners.

Kautzmann and Jaques (2019) examined the impact of an animated pedagogical agent giving metacognitive instructions to 8th-grade students on metacognitive knowledge monitoring ability and learning performance. The animated pedagogical agent was highly adaptive using students' information to vary both the training content and the frequency of intervention. Information on the students' knowledge monitoring ability, domain knowledge, and problem-solving history was tracked during every step of the task, and calculated and the probability of the students' knowledge was inferred. Reflective actions provided by the agent were prompts, feedback on inappropriate metacognitive actions, and self-explanation on metacognitive actions. The results showed positive evidence that by means of an animated pedagogical agent, learning performance and metacognitive knowledge monitoring ability were improved. This approach of adaptive metacognitive instruction including checks of whether students did what they were asked to resulted not only in higher metacognitive knowledge monitoring ability indexes but also in higher task performance. This emphasizes that by using interventions with nuanced, data-driven scaffolding strategies that adapt to students' ongoing metacognitive learning processes, learning can be influenced positively.

In summary, these studies collectively suggest an important research gap in the field of SRL: the need for developing sophisticated, adaptive SRL support for young learners who are in the phase of developing metacognitive SRL skills. From the research presented, we find that SRL support for young learners be created age-appropriate and should dynamically respond to individual learner characteristics as well as their ongoing learning performance, including learning progress. This involves advanced data analytics to create personalized learning experiences, enabling scaffolds to evolve in real time based on learners' changing needs and behaviors. This direction of research holds promise for enhancing the effectiveness of SRL support, especially for young learner between ten to twelve years old who are in need of support in CBLEs in their phase of developing metacognitive SRL skills.

5. Aim, research questions and hypotheses

Engaging in SRL activities can have a positive impact on learning progress and learning outcomes (Schunk & Greene, 2017). However, especially in CBLEs, students require support to successfully perform SRL activities (Broadbent & Poon, 2015). Metacognitive prompting has been found to be an effective way to promote metacognitive SRL strategies in CBLEs (Guo, 2022; L. Zheng, 2016) and has shown to be particularly beneficial when the prompts are adapted to the learner's individual needs (Kautzmann & Jaques, 2019; Lim et al., 2022). To address the identified research gap in SRL, the present study investigates whether adaptive metacognitive prompting successfully supports learners in lower secondary school in their SRL activities and their learning performance. Therefore, we propose an innovative approach involving 1) the development of adaptive metacognitive prompts, and 2) their integration into the highly adaptive and authentic learning environment *Brainix*. With the objective of extending previous SRL research in CBLEs by focusing on young learners and their development of metacognitive skills, the following research questions (RQs) guided the present study:

RQ1. Do adaptive metacognitive prompts influence students' (1a) self-reported metacognitive SRL activities and (1b) their online learning behavior?

RQ2. Do adaptive metacognitive prompts influence students' learning performance in terms of (2a) recall knowledge and (2b) transfer knowledge?

6. Method

6.1. Sample, study design and procedure

A total of 106 German-speaking 6th-grade students voluntarily participated in the study. Due to illness and technical difficulties, complete data sets of a total of 72 participants ($M_{age} = 10.36$ years, $SD_{age} = 0.51$ years, 37.5 % female) served for the analysis. A between-subject design with pre- and post-measurement was chosen for this research. All participants' legal guardians gave active informed consent prior to data collection. Students received a small gift for their participation in the study.

Students were invited to participate voluntarily in this research through their schools, including an invitation letter to their parents explaining the aims of the research and the procedure. While parents were informed about the aim to investigate the effects of an SRL intervention in a CBLE, learners were not explicitly informed on that matter, yet, were told that this research is about improving the presented CBLE.

Data were collected in an experimental study with a between-subjects design including pre- and post-measurements. Students in the experimental condition received metacognitive prompts ($n = 38$), while the students in the control condition did not receive any metacognitive prompts ($n = 34$). In order to start the intervention with near-equal prerequisites, stratified randomization was used to allocate students to the two conditions.

In total, students were invited to participate in a three-week learning phase, in which they would work independently in the CBLE, from at home as well as at school. Learning sessions were chosen freely in their duration and date by the students themselves. They used their own device or borrowed one from their school when working independently at school. Anonymized accounts were handed out prior to the data collection to each student.

Prior to and past this three-week learning phase, in which the learners studied in the CBLE, students were invited to participate in two data collection days, (see Fig. 1). The timeline of this study was decided based on the recommendation by Zheng (2016), who analyzed the duration of treatment as one of four key methodological features and recommended SRL interventions to take place for two to four weeks.

On the first data collection day, the students completed a test assessing prior knowledge and a test measuring their SRL skills. Specific performance levels of the subject English were collected from all students. The ratings follow the German grading system from 1 to 6, recoded for better interpretation. The participants, moreover, received an introduction to the study procedure and were shown, following Dignath and Veenman (2021), an explanation video on SRL. The experimental group received, in addition to the SRL explanation video, an explanation of the use of the metacognitive prompts in the CBLE. After studying independently for three weeks in CBLE, students were invited to a second data collection day, the post-day, on which their performance was assessed using two tests, a recall, and a transfer test.

The structure for this research procedure was derived from previous research identifying that for SRL to be appropriately measured process and product measures are necessary (Azevedo et al., 2010; Fan et al., 2022; Molenaar et al., 2023). The measurements are thus a combination of process-oriented trace data learning behavior measures (Du et al., 2023), product-oriented SRL questionnaire (Pintrich, 1991), and learning performance measures (Bannert et al., 2015).

6.2. *Computer-based learning environment and adaptive metacognitive prompts*

This research is embedded in a CBLE for lower secondary students called *Brainix*. It is an enclosed environment in which students are guided step-by-step through exercises with audio files, texts, grammar entries, and illustrations. Each exercise is evaluated by the system. During the study, the students worked in a learning unit estimated for 3.5 hours of study time. The learning unit trained fundamentals of text writing, grammar, and vocabulary of English as a first foreign language integrated into the learning scenario of an adventure to a haunted castle.

In total, three prompts and a calendar were created to adaptively promote SRL in the CBLE. They are based on Zimmerman's (2000) and Winne and Hadwin's (1998) model of SRL and were created using a Learner-Centered Design approach (Tsvyatkova & Storni, 2019) and the Design Thinking approach (Plattner et al., 2009). The Learner-Centered Design ensured that the design was guided by educational and learning psychological theory and adapts to learners' needs, while Design Thinking emphasizes iterative prototyping and user feedback. Learners were inherently involved in the design process to ensure the usability and effectiveness of the adaptive metacognitive prompts. With this approach, it was our goal to follow the idea of co-design and collaboration between researchers and children (Grammenos & Antona, 2018).

The initial development process was inspired by a structured four-phase user-centered Design Thinking approach. In the research phase, a literature review on goal setting, planning, and reflection in SRL support and interviews with educators informed the initial prompt design. During design exploration, early prototypes were developed based on the theoretical frameworks and the empirical findings. In the prototype building and visualization phase, visual elements such as icons, progress bars, and drag-and-drop features were integrated to support comprehension and engagement (David & Sulaiman, 2021). Finally, in the phase of prototype evaluation, a usability test with 6th-grade students ($N = 10$) was conducted. Students participated in a remote session where they described what they saw in the prototype, its purpose, and whether there were some unclear aspects of the prototype. In total, the usability test with the learners took about 30 minutes. Minor ambiguities were identified and resolved before integration into the CBLE.

Following this phase of prototype building, prototype evaluation, and prompt integration into the CBLE, a quasi-experimental research was conducted (the authors of the present paper, in review), measuring the effects on students' SRL activities during one learning session using the think-aloud method. The think-aloud method was used to assess in-depth how lower secondary school learners ($N = 33$) engaged in prompted and unprompted utterances of metacognitive SRL activities. Based on the results of the coded utterances, more interactive elements were implemented into the prompts, using more and clickable goal icons, less text, and required interaction formats. In the present study, the prompts were presented at the beginning and at the end of the learning unit which the students worked on over three weeks. The calendar was available throughout the whole learning period.

Two aspects, furthermore, seemed important from the conducted research and prior research to focus on. First, following, Geurten et al. (2018), Braad et al. (2022), and Pape and Thomas (in review), the prompts should be designed to foster domain-general metacognitive strategies, mainly independent of specific subjects. They aim to enhance students' overall learning rather than focusing solely on task-specific guidance. The focus was, therefore, transferred to more domain-general SRL strategies. Second, following Koszalka et al. (2019) and the authors of the present study (in review), the prompts are designed for interaction, requiring responses from students. These responses are analyzed and stored, enabling the system to personalize learning experiences based on the data collected and the progress of each individual. The prompts, therefore, in this research consist of a structured response format, which required the learners to answer and would not allow them to simply continue without a prompt reaction.

From these iterations, the three prompts, the *set goal prompt*, the *prioritize prompt*, the *reflect prompt*, and the calendar *goals planner* presented in the current research are derived. All prompts were presented to the learners in German, as all of them were beginners in the English language. For clarity in this paper, they were translated into English.

In the *set goal prompt* (Fig. 2), students are asked to think about the

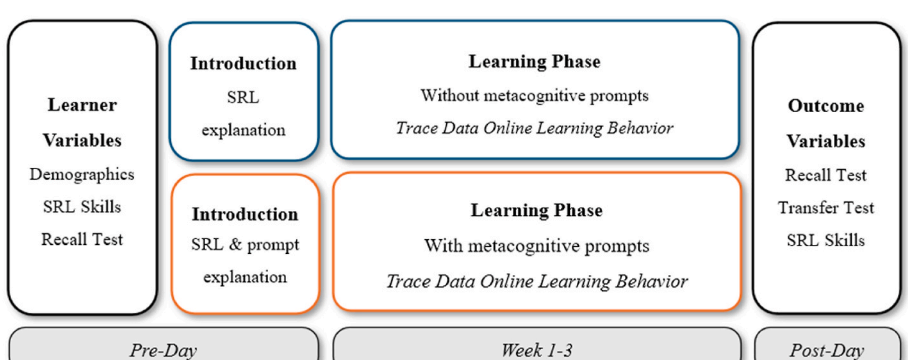

Fig. 1. Design and study procedure.

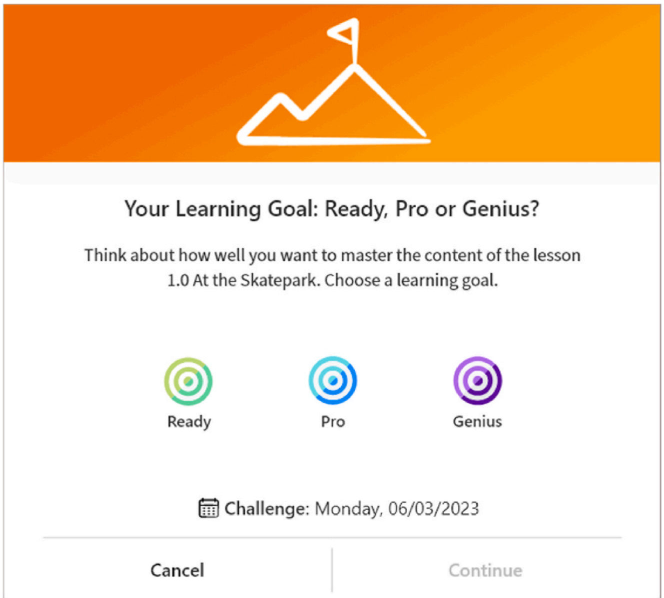

Fig. 2. The set goal prompt in the learning environment.

extent to which they want to master the content and thus become *challenge-ready*, the minimum level goal, *pro*, the advanced level goal, or *genius*, the highest level goal. To continue, they need to choose one of the goal icons by clicking on it. Once a goal was chosen, the learners continued to the next screen. The *prioritize prompt* (Fig. 3), is designed to give an initial overview of the upcoming learning unit and tasks and to guide them in personalizing their learning goals. By dragging and dropping, students prioritize three learning contents and thereby, decide for their individual preferences on the learning content.

The *goals planner* (Fig. 4) contains action plans with learning tasks recommended as the next learning action. Action plans are adapted to each student's individual progress, goals, and prioritization, enabled through an algorithm that calculates the learning progress of individual learners, models their learning, and then makes exercise recommendations that are appropriate to their level of knowledge. Each completion of a task generates a booking to the learners' knowledge data bank

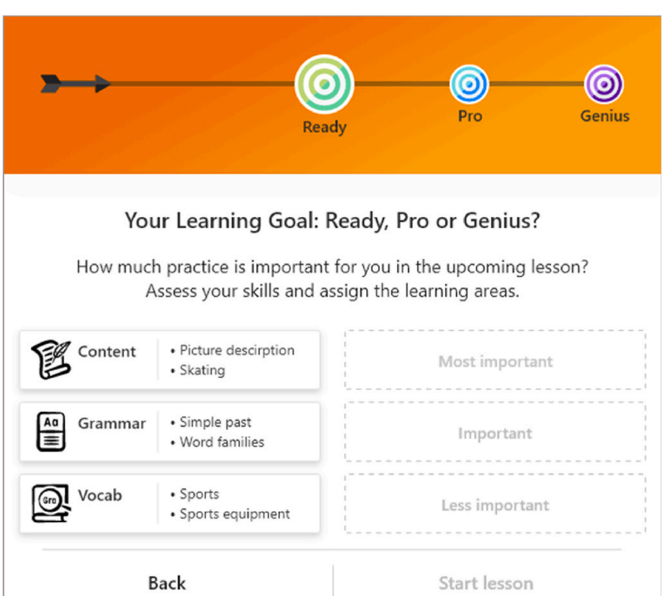

Fig. 3. The prioritize prompt in the learning environment.

which includes task correctness and level of difficulty of the task ordered by content. The knowledge database contains, for instance, a content booking in the grammar category on the grammar topic 'simple past' or 'comparison of adjectives' for English language learning. The difficulty level of the task is categorized according to an adapted version of the taxonomy by Bloom et al. (1956) by assigning each task to a certain level in the taxonomy. From the estimates of the total time needed to achieve a task, learning tasks are preselected and proposed to the learners in the form of calendar entries planned in 20-min increments. Through categorization and time calculation, the system continuously tracks the learner's learning progress on a task-by-task basis, identifying strengths and weaknesses and recommending appropriate tasks to train topics that had been completed with low task correctness. The *goals planner* as well as the learning environment *Brainix* thereby continually adapts to the learner's progress and needs, allowing for adaptive and supported planning and learning. By clicking on the items, students can modify the action plans for their learning week according to their preferences. They were given the overview of the tasks and subsequently, encouraged through the prompts to plan their week timewise and content-wise. Content was presented and recommended based on the identified learning issues through the knowledge database.

The *reflect prompt* (Fig. 5) reports on students' individual progress and offers them a choice of next steps to continue their learning paths. All prompts are adaptive to the student's progress and include learning goals visualized by a progress bar and goal icons. They were presented to the students in German language.

6.3. Measurements

6.3.1. SRL questionnaire

To examine the first research question on the influence of metacognitive prompting on the learners' SRL (RQ1a), two contextualized scales of the MSLQ (Pintrich, 1991) were administered in a pre-post design. The two scales Metacognitive Self-regulation (MSR; 12 items) and Time and Resource Management (TSE; 8 items) were selected due to the absence of suitable alternatives of questionnaires concerning metacognition and time management for lower secondary school students (Koivuniemi et al., 2021). The items in these two scales were translated from English to German and were subsequently adapted for the present research in the context of learning. In the pretest, the items referred to the context of learning in everyday school life (e.g. translated from German MSR1_11: When I study for class, I set myself goals to manage my activities in each learning phase). The answers are used as an indicator of the students' SRL skills prior to the study. In the posttest, items were adjusted to the context of learning in the CBLE (e.g. MSR1_11: When I study in *Brainix*, I set myself goals to manage my activities in each learning phase). This context differentiation is a result of teachers' reports that students rarely learn in CBLEs in everyday school life and therefore cannot evaluate their SRL skills in a digital context prior to the study. For the posttest, however, the items had to be specific to the CBLE context as analog school lessons were taking place simultaneously with the study. The items did not require any further modifications, as the short items were age-appropriate. As shown in Table 1, the contextualized scales of the MSLQ in the pre-and post-test were reliable, and additionally, the reliability values were similar to those when originally validated (Pintrich, 1991).

6.3.2. SRL log data

To investigate the second part of the first research question (RQ1b), the software LogRocket (2022) was used to collect event-based trace data logging students' online SRL learning behavior in the CBLE. Following Du et al. (2023), the extracted data were combined with empirical findings to classify SRL processes and subprocesses. In total, four indicators of the students' learning behavior were assessed, and collected during the three weeks of learning in the CBLE. This includes login duration, login frequency, learning progress, and learning

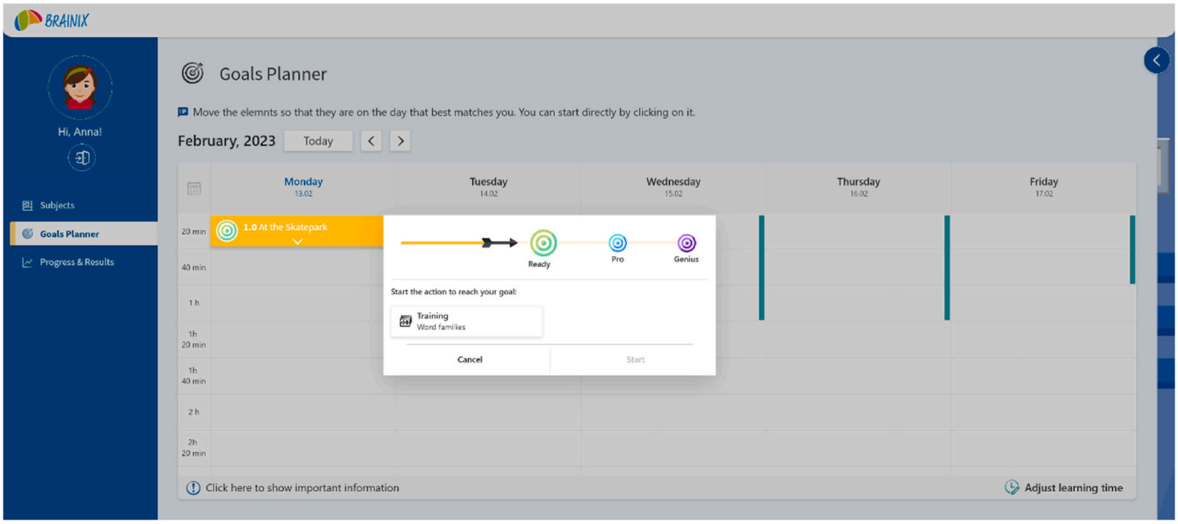

Fig. 4. The goals planner in the learning environment.

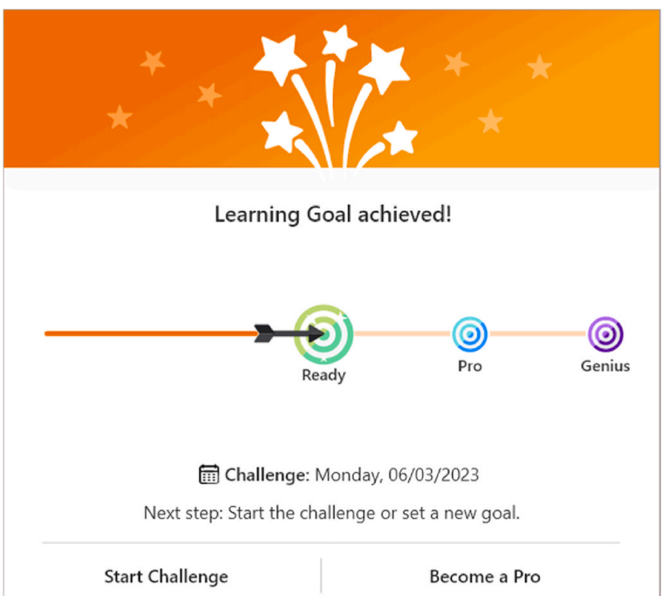

Fig. 5. The reflect prompt in the learning environment.

Table 1
Reliability of scales on metacognitive self-regulation and time management of the MSLQ.

Scale	Pretest			Posttest		
	N	Items	*α*	*N*	Items	*α*
MSR	105	12	0.663	95	12	0.736
TSE	105	8	0.638	95	8	0.685

regularity. Previously, these indicators of learning behavior have been identified as indicators for SRL activities (Kim et al., 2018; Rodrigues et al., 2019; van Halem et al., 2020; Wong et al., 2021; Jansen et al., 2019).

6.3.3. Learning performance tests

To investigate the second research question on the influence of metacognitive prompting on learning performance (RQ2), two tests were developed with the help of teachers. A recall test, in which knowledge was tested using fill-in-the-gaps and multiple-choice exercises, and a transfer test, in which the students were asked to write a long text in the form of an e-mail on the contents of the lesson. Previous research has shown that scaffolding of SRL was less likely to influence recall performance and more likely to impact transfer performance (Bannert, 2007; Lim et al., 2021; Müller & Seufert, 2018; Sonnenberg & Bannert, 2015). Therefore, both performance tests were administered. The recall test was given to the students as a pre-and post-test in order to determine both prior knowledge and learning gain. In total, both tests showed highly significant correlations with the learners' English grades and with each other, indicating a good validity of both knowledge tests.

6.4. Data-analysis

For the questionnaire, the recall and transfer tests, descriptives were calculated. Students were included, if all scales, both recall tests (pre and post) and the transfer test, had been filled out. For the transfer test, an evaluation scheme was developed by researchers and teachers. To assess the interrater reliability, a research assistant independently evaluated fifteen tests, representing 21 % of the total amount of participants. A very high intercoder reliability (Cohen's $\kappa = 0.99$) was determined.

Concerning the learners' online learning behavior, login time and login duration were calculated. Learning progress in the lesson was determined at the end of the study. From these values, login frequency and learning regularity were calculated. As these online learning behavior measures correlate with the time management scale of the MSLQ, the variables of online learning behavior can be viewed as valid. If a student logged in several times a day, it was calculated as different logins. Learning regularity was calculated as the standard deviation of the average learning interval, adapted from Jo et al. (2015). Scores obtained with this method correlated highly with other measures of learning behavior and the Time Management Scale. The average learning interval can be expressed as shown:

$$\overline{\Delta t_i} = \frac{\sum_{i=1}^{n-1} \Delta t_i}{n}$$

The value Δt_i stands for the time interval between two learning phases, i.e. the duration of a learning break (in days), including also the days from the start of the data collection period to the first login and from the last login to the end of the data collection period. The value n represents the number of learning breaks between the first and last login. The standard deviation of the learning interval was calculated as follows:

$$S_t = \sqrt{\frac{\sum_{i=1}^{n-1} (t_i - \overline{\Delta t_i})^2}{n-1}}$$

For inferential analyzes, the data were checked for normality and outliers. Separate t-tests for independent and dependent variables were calculated. As the questionnaire items differed in their context, either the context of everyday school life or the context of the CBLE, no repeated measures ANOVA was conducted for self-reported SRL skills. An ANOVA for repeated measures was performed for learning gain. To further analyze interaction effects, moderator analyzes were conducted by means of the PROCESS macro by Hayes (2018) which applies ordinary least squares regression, providing unstandardized coefficients for all effects. Bootstrapping with 5000 iterations samples together with heteroscedasticity consistent standard errors (HC3; Davidson & MacKinnon, 1993) was employed to calculate confidence intervals and inferential statistics. The assumption of normal distribution can, therefore, be neglected. Effects were considered significant if the confidence interval did not include zero. As assessed by visual inspection of the scatterplots after LOESS smoothing, the relationship between all variables included in the moderation analysis was approximately linear.

7. Results

Firstly, descriptive and inferential analyzes of the questionnaire, online learning behavior and learning performance between the treatment groups are presented. Secondly, factors that may influence the use of the prompts and thereby, the learning outcomes, are analyzed.

7.1. Group differences in learner characteristics

Descriptive and inferential analyzes for learner characteristics are shown in Table 2. Independent sample t-tests revealed no significant differences between the groups for learner characteristics assessed in the pretest MSLQ scales, the prior knowledge measured in the pretest recall test, and the students' performance level, the average of learners' current English grades, prior to the study. Additionally, the students' experience in computer use and *Brainix* use was collected to detect differences prior to the intervention, however, no significant differences were found.

7.2. Effects on self-regulated learning and learning outcomes

To investigate the first research question, the effects of the metacognitive prompts on the students' SRL skills and their online behavior were examined. In total, as descriptive analyzes of the log data show, students worked on average a total of 4h 3min (SD = 1h 56min) in the learning environment and logged in 6.3 times on average ($SD = 3.2$). When they logged in, the learners worked in the environment for 00:45:13 (SD = 00:13:19) on average per day. Overall, students had 4.14 ($SD = 2.43$) pause intervals on average in the data collection period, in which they did not log into the learning environment, representing a learning regularity of 4.64 days ($SD = 3.04$). This indicates that every four to five days, the students worked in the learning environment.

Investigating group effects on students' online learning behavior, a mixed ANOVA including the condition and all online learning behavior measures was conducted. While both groups show a high value in lesson progress, the control group ($M_{CG} = 97.91$; $SD_{CG} = 10.00$) outperformed the experimental group ($M_{EG} = 86.26$; $SD_{EG} = 21.89$) significantly ($t(70) = - 0.85$, $p < 0.001$). For login frequency, duration, and learning regularity no significant group differences were found.

Examining students' self-reported SRL skills, independent sample t-tests revealed significant group differences in the Metacognitive Self-regulation Scale ($t(70) = 2.14$, $p < 0.05$). No group differences were found in the Time Management Scale ($t(70) = 1.1$, $p = 0.278$). Descriptive analyses show that scale means for the context of everyday school life ($M_{MSR1} = 49.39$, $SD_{MSR1} = 9.4$; $M_{TSE2} = 42.56$, $SD_{TSE2} = 7.69$) are higher than for the context of CBLEs ($M_{MSR2} = 46.54$, $SD_{MSR2} = 10.69$; $M_{TSE2} = 40.28$, $SD_{TSE1} = 7.43$).

To investigate the second research question, the effect of metacognitive prompting on learning outcomes, learning gain was determined. An ANOVA for repeated measures found a significant difference between pre-test scores ($M_{preRC} = 11.56$, $SD_{preRC} = 0.31$) and post-test scores ($M_{postRC} = 89.23$, $SD_{postRC} = 1.51$) concerning recall knowledge, $F(1, 70) = 2587.72$, $p < 0.001$. This suggests that the lesson in the CBLE *Brainix* successfully yielded pre-to-post learning gains. To investigate group differences, a mixed ANOVA revealed no main effects of the condition on learning outcomes. Descriptives show that the control group performed better both in the recall knowledge and the transfer knowledge test than the experimental group, resulting in a negative effect size for both recall knowledge (Cohen's $d = -0.26$) and transfer knowledge (Cohen's $d = -0.21$), indicating small negative effects of the metacognitive prompts. In Table 3, we present all descriptive and inferential statistics for all dependent variables.

7.3. Aptitude-treatment-effects on learning outcomes

The non-observance of significant main effects of metacognitive prompting could be explained by aptitude-treatment effects (Cronbach & Snow, 1977). It might be the case, that only a subsample benefited from the metacognitive prompting while it might have been hindering for other participants. To determine whether the interaction between treatment and learner characteristics significantly influences recall or transfer knowledge, moderation analyzes were performed. The results of these analyzes are reported in Table 4. Key interactions are detailed

Table 2
Descriptive and inferential statistics of independent variables.

	EG (n = 38)		CG (n = 34)		Two-tailed p-value	Cohen's d
	M	SD	M	SD		
Learner Variables						
Prior performance level	4.16	0.89	4.18	0.87	0.929	−0.021
Computer experience	3.55	0.86	3.47	0.79	0.676	0.099
Brainix experience	0.34	0.48	0.35	0.49	0.925	−0.022
Self-regulation						
MSR_1	49.92	8.97	48.79	9.96	0.615	0.119
TSE_1	43.71	7.27	41.26	8.04	0.180	0.320
Learning Performance						
Prior recall knowledge	10.18	2.10	10.21	2.94	0.971	−0.009

Table 3
Descriptives and inferential statistics of dependent variables.

	EG (n = 38)		CG (n = 34)		One-tailed p-value	Cohen's d
	M	SD	M	SD		
Self-regulation						
MSR2	49.03	10.85	43.76	9.95	0.018	0.504
TSE2	41.18	7.66	39.26	7.13	0.138	0.259
Navigation behavior						
Login duration	3:46:22	1:47:17	4:20:39	2:04:05	0.106	−0.297
Login frequency	6.13	3.06	6.44	3.48	0.345	−0.095
Learning regularity	4.37	2.76	4.95	3.35	0.212	−0.190
Progress in lesson	86.26	21.89	97.91	10.00	0.003	−0.672
Learning outcomes						
Post-test recall	12.47	3.22	13.38	3.72	0.135	−0.262
Transfer	6.37	3.85	7.12	3.14	0.186	−0.212

Table 4
Results of moderation analyzes: Overall models and moderator effects.

	Regression analysis			Moderation analysis			
	R^2	*F*	*p*	R^2	*F*	*p*	*95 % CI*
Recall							
Treatment & performance level	16.81	3.58	0.018	0.5	0.35	0.554	−0.932; 2.587
Treatment & prior knowledge	25.24	10.42	<0.001	0.5	0.63	0.429	−0.263; 0.805
Treatment & SRL skills	2.37	0.55	0.654	0.5	0.26	0.614	−0.163; 0.096
Transfer							
Treatment & performance level	21.22	6.43	<0.001	5.97	6.01	0.017	−3.569; −0.459
Treatment & prior knowledge	8.81	4.44	0.006	2.77	2.08	0.156	−0.241; 1.054
Treatment & SRL skills	1.91	0.51	0.679	0.7	0.43	0.514	−0.163; 0.085

Note. R^2 in percentage.

below.

For recall knowledge, a significant overall model was found for the interaction of treatment and performance level, $F(3, 68) = 3.58$, $p = 0.018$, predicting 16.81 % of the variance. The moderation analysis, however, showed that performance level did not significantly moderate the effect between treatment and recall knowledge, $\Delta R^2 = 0.5$ %, $F(1, 68) = 0.354$, $p = 0.554$, 95 % CI[-0.932; 2.587]. For prior knowledge, a significant overall model was found for the interaction with treatment, and in terms of recall knowledge, $F(3, 68) = 10.416$, $p < 0.001$, predicting 25.24 % of the variance. Moderation analysis, however, showed that prior knowledge did not significantly moderate the effect between treatment and recall knowledge, $\Delta R^2 = 0.5$ %, $F(1, 68) = 0.632$, $p = 0.429$, 95 % CI[-0.263; 0.805]. Analyzes did not show that SRL skills moderated the effect between treatment and recall knowledge significantly, $\Delta R^2 = 0.5$ %, $F(1, 68) = 0.256$, $p = 0.614$, 95 % CI[-0.163; 0.096].

For transfer knowledge, a significant overall model was found for the interaction of treatment and performance level, $F(3, 68) = 6.43$, $p < 0.001$, predicting 21.22 % of the variance. The moderation analysis showed, furthermore, that the performance level did significantly moderate the effect between treatment and transfer knowledge, $\Delta R^2 = 5.97$ %, $F(1, 68) = 6.014$, $p = 0.017$, 95 % CI[-3.569; −0.459]. For prior knowledge, a significant overall model was found for the interaction with treatment, and in terms of transfer knowledge, $F(3, 68) = 4.443$, $p = 0.006$, predicting 8.81 % of the variance. Moderation analysis, however, showed that prior knowledge did not significantly moderate the effect between treatment and recall knowledge, $\Delta R^2 = 2.77$ %, $F(1, 68) = 2.079$, $p = 0.156$, 95 % CI[-0.241; 1.054]. For SRL skills, no significant overall model, nor a significant moderator effect was found.

By means of the Hayes Process macro (2018), the Johnson-Neyman significance region was detected for the moderator value below 23.61 % and above 76.39 % respectively. To visualize this interaction effect, an adapted Johnson-Neyman-Plot (Johnson & Neyman, 1936) was computed indicating a significant conditional effect of treatment on transfer knowledge, if the moderator performance level was outside the interval [3.64; 7.89], $p < 0.05$ (see Fig. 6). These findings from the Johnson-Neyman significance region in combination with adapted Johnson-Neyman-Plot indicate that those with low performance levels in particular were significantly limited in terms of their transfer knowledge performance by the metacognitive prompting in the CBLE *Brainix*.

8. Discussion

The aim of the study was to investigate the effects of adaptive metacognitive prompts on young learners' SRL and learning performance over a period of three weeks. To obtain these results, a pre-post measurement and between-subject design study assessed SRL through self-reports and online log data, as well as learning performance by means of a recall and a transfer knowledge test.

8.1. Implications of findings on self-regulated learning

Regarding the first research question, analyzes of the self-reports reveal that metacognitive prompting significantly increased the learners' metacognitive SRL in the context of digital learning. These findings, analyzed by means of the scale Metacognitive Self-regulation of the MSLQ, are in line with our expectations and previous findings

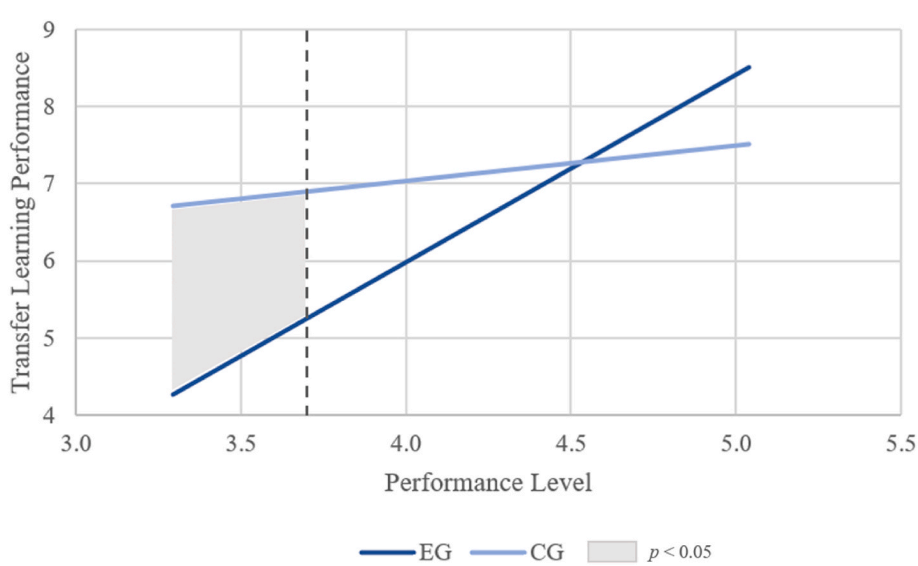

Fig. 6. Adapted Johnson-Neyman-plot of interaction effect.

(Delen et al., 2014; Guo, 2023; Lai & Hwang, 2016). All metacognitive prompts including the goals planner were adaptive to the students' goals and progress including interactive progress bars and adapting goal icons. These findings indicate that guiding lower secondary school students to personalize and prioritize their goals as well as to monitor and reflect on their progress by means of metacognitive prompting helps them to engage in SRL skills.

The metacognitive prompting did not, however, increase the learners' time management abilities measured by means of the second scale in the self-report and the learners' online behavior. These findings may shed light on the *goals planner*, in particular, that had been created to support learners in their strategic planning. It has been noted previously that time management is an essential self-regulatory process, by which students actively determine when and for how long they will pursue activities deemed necessary for the achievement of their academic goals (Wolters & Brady, 2021). However, planning activities, in particular, can lead to cognitive load (Seufert, 2018), hindering the students' learning process if instructions are created too complex (Sweller et al., 1998) Reducing the complexity of planning features in CBLEs may be achieved by providing a training phase prior to sole calendar use ensuring basic knowledge of calendar use.

Surprisingly, the control group made significantly more progress in the lesson than the experimental group. Prior studies have suggested that while gamification elements have been shown to enhance desired motivational, behavioral, and learning outcomes (Zainuddin et al., 2020), some can overlap with elements of SRL support (Raleiras et al., 2020). Rewards such as badges, coins, or stars can be used to support planning, self-monitoring, collaboration and comparison, and self-evaluation (Tang & Kay, 2014). Higher learning progress among those without metacognitive prompting may indicate that the gamified elements may not have been well aligned with the SRL support, causing unnecessary confusion for the experimental group. Although the advanced learning progress of the control group did not result in significantly improved learning outcomes, future research requires a more rigorous exploration of factors that interact with the SRL support in the CBLE.

8.2. Implication of findings on learning performance

Regarding the second research question, findings show that learners supported by metacognitive prompting did not significantly improve their learning performance compared to learners who did not receive prompts. While these results concerning the effects of SRL support on recall knowledge are in line with previous studies (Bannert et al., 2015; Bannert & Mengelkamp, 2008; Engelmann & Bannert, 2021), the findings in terms of SRL support on transfer knowledge contradict previous research (Lim et al., 2021; Müller & Seufert, 2018; Sonnenberg & Bannert, 2015). These analyzes of previous research were, however, conducted mainly in settings with learners in higher education. Among younger learners, it was previously found that while SRL strategies were fostered, no transfer effects on achievement were detected (Benick et al., 2021). The present research focused on a language learning context. Future research may include this intervention in a CBLE context of mathematics as higher effect sizes were found in intervention studies in the context of well-structured subjects (Dignath et al., 2008).

Post-hoc interaction analyzes indicate differential effects of the adaptive metacognitive prompts for high and low achieving learners. While high achieving learners seem to have rather profited from the support of prompts in terms of transfer knowledge, as reported previously (Hsu et al., 2017; Kramarski et al., 2013; McCarthy et al., 2018; van Dijk et al., 2016), the significantly negative effects on transfer performance for low achieving learners point to a result discussed as the Matthew effect. Previous studies that described the Matthew effect hypothesized that SRL instructions are more likely to help high achievers in general, resulting in even greater inequalities (Dörrenbächer & Perels, 2016; Lau, 2022). The assumption that low-achieving learners require more support to benefit from SRL instructions because they show lower SRL competencies (Bai et al., 2021; Lau, 2022) was, however, not substantiated by the results of the study. Post-hoc analyzes indicate no significant moderation of SRL competencies between the condition and learning performance. Other studies have suggested that prior knowledge influences the students' learning performance (e.g., Thompson & Zamboanga, 2003), however, no interaction effects of prior knowledge were found in the present study. Prior achievement levels have been widely shown to influence future achievement levels (Hemmings & Kay, 2010), however, to reduce these inequalities, support for low-achieving students in particular needs to be addressed in future research.

In order to effectively support all students by means of metacognitive prompting, adjustments especially valuable for low-achieving students can be realized within the design of the prompts. van Dijk et al. (2016) found that average and low-ability students rarely made use of the prompts. The absence of effects on learning performance due to student compliance has been suggested before (Müller & Seufert, 2018; van Alten et al., 2020). In the present study, it cannot be ruled out that this might have affected the results. However, as it has been shown that compliance is increased when students interact with the prompts (Bannert et al., 2015), the prompts in the present study were created highly interactive. In order to effectively use the prompts, learners may first need to realize that the help offered is necessary, which they cannot if they lack self-assessment skills (van Dijk et al., 2016). Future research should integrate measures in the design of the prompts that control the quality of the prompts use by means of checks for inadequate behavior, as exemplified by Kautzmann and Jaques (2019).

In addition, the relationship between motivational variables, metacognitive prompts, and learning performance remains to be explored. Bai and colleagues (Bai et al., 2021) found that self-efficacy and a growth mindset were crucial predictors of strategy use, indicating that students who believe that their skills can be improved through effort and practice are more likely to undertake efforts, seek challenges, and persevere in the face of setbacks. Some initial findings indicate that growth mindset interventions may be particularly helpful for struggling students (Macnamara & Burgoyne, 2022; Yeager et al., 2019); however, this and its influence on the effective use of metacognitive prompts, needs further investigation.

8.3. Limitations and future research

The present study has some clear limitations and should be addressed in future research. Firstly, the generalizability of the present study's findings is limited. The presented data were collected from a single secondary school in Germany, a *Gymnasium*, Germany's highest academic school type. To draw conclusions that are applicable to lower-achieving students, it is essential that future studies incorporate participants from a broader range of school types. Furthermore, the quasi-experimental design of the study required the continuous presence of participants across data collection of three weeks of. However, due to student absences resulting from illness, not all participants who initially took part could be included in the final analyzes. In addition, technical issues reported by some learners while using the CBLE necessitated the exclusion of these cases from the dataset. To support more robust generalizations concerning learner characteristics, future research should include larger and more diverse samples. Given the difficulty of collecting and analyzing data from young learners, the present study provides first exploratory results for future studies with this age group.

Secondly, in order to increase the effects on SRL activities and learning performance, learners should work in the CBLE during school as their main learning task. Due to strict school policies, students voluntarily participated in this study outside of the classroom. For students to adapt to new learning situations (Gašević et al., 2017) and to work within the environment with reduced extraneous cognitive load (Seufert, 2018), learning sessions in the CBLE in the classroom environment seem beneficial to investigate.

Future studies, thirdly, need to include means to measure individual effects of each prompt and quality of the prompt usage. Prior research by De Haas et al. (2022) indicated a decline in children's task engagement over time, aligning with the novelty effect describing learners to be excited in the beginning when using a new technology (Kanda et al., 2004). Using advanced data mining or eye tracking (Fan et al., 2022; Sim & Bond, 2021) of SRL activities combined with think-aloud data to receive multimodal data (Molenaar et al., 2023), may reveal activities that could not be observed in the present study. Furthermore, an SRL questionnaire validated for young learners and digital learning contexts can be helpful. Combining these multimodal data will aid future research that seeks to clarify students' engagement in metacognitive SRL activities and to determine how adaptive SRL support needs to be designed to effectively improve learning in CBLEs.

9. Conclusion

The main purpose of the present study was to investigate the effects of adaptive metacognitive prompts including goal setting, strategic planning, and progress evaluation on SRL activities and learning performance in young learners in an authentic CBLE. Results show that the learners' self-reported metacognitive SRL skills were significantly enhanced by means of metacognitive prompting. However, no effects of the metacognitive prompts were found on recall or transfer knowledge when all learners were included. Findings from moderation analyzes indicate that performance level significantly moderated the relation between the condition and the transfer learning performance, surprisingly negatively impacting especially students with low-performance levels. These findings highlight the importance of adaptivity of SRL support to the students' prior achievement levels, emphasized by the results in the present study that neither prior knowledge nor prior SRL skills moderated the effect of the prompts on learning performance. To further advance research on the development of SRL in young learners, metacognitive prompts need to be more rigorously checked for appropriate usage, additional measures such as mining behavioral SRL data and eye-tracking can be beneficial. Also, motivational variables such as self-efficacy and growth mindset that influence prompt usage remain to be explored.

CRediT authorship contribution statement

Rebecca Pape: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Joachim Thomas:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Selection and participation of children

All participants included in the study were students from public schools in Bavaria, Germany. The main data collection of the study took place at the students' homes, each student learning individually by themselves for three weeks. Pre and post data collections were administered at public schools, following the schools' regulations. All students' legal guardians were contacted to obtain written consent permitting the data collection, data processing and anonymized publication. Children were fully informed about the study process and procedures. Their participation was voluntary and informed that they could withdraw their consent for the data collection at any time without further consequences. The university's Ethics Committee approved the data collection in advance. The approval can be found under the approval number 171–2023.

Only students in grade 6 (German lower secondary school) were invited to participate in the study as learning units were designed to fit the regional curriculum. Using stratified randomization, the learners were allocated to the prompted and unprompted condition. The learners received a small gift for their participation.

Declaration of competing interest

We have no conflicts of interest to disclose. The study has been conducted according to the principles expressed in the Declaration of Helsinki and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The learning environment including the integration of the adaptive metacognitive prompts was provided by Brainix GmbH. The company was not involved in the study design, data collection, analysis, or the writing of the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcci.2025.100740.

Data availability

Data will be made available on request.

References

Askell-Williams, H., Lawson, M. J., & Skrzypiec, G. (2012). Scaffolding cognitive and metacognitive strategy instruction in regular class lessons. *Instructional Science, 40*(2), 413–443. https://doi.org/10.1007/s11251-011-9182-5

Azevedo, R., Bouchet, F., Duffy, M., Harley, J., Taub, M., Trevors, G., Cloude, E., Dever, D., Wiedbusch, M., Wortha, F., & Cerezo, R. (2022). Lessons learned and future directions of MetaTutor: Leveraging multichannel data to scaffold self-regulated learning with an intelligent tutoring system. *Frontiers in Psychology, 13*. https://doi.org/10.3389/fpsyg.2022.813632

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*(3), 344–370. https://doi.org/10.1016/j.cedpsych.2003.09.002

Azevedo, R., Moos, D. C., Johnson, A. M., & Chauncey, A. D. (2010). Measuring cognitive and metacognitive regulatory processes during hypermedia learning: Issues and challenges. *Educational Psychologist, 45*(4), 210–223. https://doi.org/10.1080/00461520.2010.515934

Azevedo, R., Witherspoon, A., Chauncey, A. D., Burkett, C., & Fike, A. (2009). MetaTutor: A MetaCognitive tool for enhancing self-regulated learning. In *2009 AAAI fall symposium series* (pp. 14–19). https://cdn.aaai.org/ocs/995/995-4214-1-pb.pdf.

Bai, B., Wang, J., & Nie, Y. (2021). Self-efficacy, task values, and growth mindset: What has the most predictive power for primary school students' self-regulated learning in English writing and writing competence in an Asian Confucian cultural context? *Cambridge Journal of Education, 51*(1), 65–84. https://doi.org/10.1080/0305764X.2020.1778639

Bannert, M. (2007). *Metakognition beim Lernen mit Hypermedien*. Waxmann Verlag.

Bannert, M. (2009). Promoting self-regulated learning through prompts. *Zeitschrift für Padagogische Psychologie, 23*(2), 139–145. https://doi.org/10.1024/1010-0652.23.2.139

Bannert, M., & Mengelkamp, C. (2008). Assessment of metacognitive skills by means of instruction to think aloud and reflect when prompted. Does the verbalisation method affect learning? *Metacognition and Learning, 3*(1), 39–58. https://doi.org/10.1007/s11409-007-9009-6

Bannert, M., & Reimann, P. (2012). Supporting self-regulated hypermedia learning through prompts. *Instructional Science, 40*(1), 193–211. https://doi.org/10.1007/s11251-011-9167-4

Bannert, M., Sonnenberg, C., Mengelkamp, C., & Pieger, E. (2015). Short- and long-term effects of students' self-directed metacognitive prompts on navigation behavior and learning performance. *Computers in Human Behavior, 52*, 293–306. https://doi.org/10.1016/j.chb.2015.05.038

Benick, M., Dörrenbächer-Ulrich, L., Weißenfels, M., & Perels, F. (2021). Fostering self-regulated learning in primary school students: Can additional teacher training enhance the effectiveness of an intervention? *Psychology Learning & Teaching, 20*(3), 324–347. https://doi.org/10.1177/14757257211013638

Biswas, G., Segedy, J. R., & Bunchongchit, K. (2016). From design to implementation to practice a learning by teaching system: Betty's Brain. *International Journal of Artificial Intelligence in Education, 26*(1), 350–364. https://doi.org/10.1007/s40593-015-0057-9

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives handbook I: Cognitive domain*. Ing: David McKay Company.

Bouchet, F., Harley, J. M., & Azevedo, R. (2018). Evaluating adaptive pedagogical agents' prompting strategies effect on students' emotions. In R. Nkambou, R. Azevedo, & J. Vassileva (Eds.), *Lecture Notes in computer science: Vol. 10858, intelligent tutoring systems: 14th international conference, ITS 2018, Montreal, QC, Canada, june 11–15, 2018: Proceedings* (pp. 33–43). Springer. https://doi.org/10.1007/978-3-319-91464-0_4.

Braad, E., Degens, N., Barendregt, W., & Ijsselsteijn, W. (2022). Improving metacognition through self-explication in a digital self-regulated learning tool. *Educational Technology Research & Development, 70*(6), 2063–2090. https://doi.org/10.1007/s11423-022-10156-2

Broadbent, J., & Poon, W. L. (2015). Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic review. *The Internet and Higher Education, 27*, 1–13. https://doi.org/10.1016/j.iheduc.2015.04.007

Bronson, M. B. (2000). Recognizing and supporting the development of self-regulation in young children. *Young Children, 55*(2), 32–37.

Ceron, J., Baldiris, S., Quintero, J., Garcia, R. R., Saldarriaga, G. L. V., Graf, S., & La Fuente Valentin, L. D. (2021). Self-regulated learning in massive online open courses: A state-of-the-art review. *IEEE Access, 9*, 511–528. https://doi.org/10.1109/access.2020.3045913

Chen, J., Lin, C.-H., Chen, G., & Fu, H. (2023). Individual differences in self-regulated learning profiles of Chinese EFL readers: A sequential explanatory mixed-methods study. *Studies in Second Language Acquisition, 45*(4), 955–978. https://doi.org/10.1017/S0272263122000584

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods: A handbook for research on interactions* (pp. 1–14). Irvington.

David, M., & Sulaiman, N. A. (2021). The functions of visualization in assisting reading comprehension among young learners. *International Journal of Academic Research in Business and Social Sciences, 11*(10). https://doi.org/10.6007/IJARBSS/v11-i10/10983

Davidson, R., & MacKinnon, J. G. (1993). *Estimation and inference in econometrics*. Oxford University Press.

de Haas, M., Vogt, P., van den Berghe, R., Leseman, P., Oudgenoeg-Paz, O., Willemsen, B., de Wit, J., & Krahmer, E. (2022). Engagement in longitudinal child-robot language learning interactions: Disentangling robot and task engagement. *International Journal of Child-Computer Interaction, 33*, Article 100501. https://doi.org/10.1016/j.ijcci.2022.100501

Delen, E., Liew, J., & Willson, V. (2014). Effects of interactivity and instructional scaffolding on learning: Self-regulation in online video-based environments. *Computers & Education, 78*, 312–320. https://doi.org/10.1016/j.compedu.2014.06.018

Diamond, A. (2016). Why improving and assessing executive functions early in life is critical. In J. A. Griffin, P. D. McCardle, & L. Freund (Eds.), *Executive function in preschool-age children: Integrating measurement, neurodevelopment, and translational research* (pp. 11–43). American Psychological Association. https://doi.org/10.1037/14797-002.

Dignath, C., Buettner, G., & Langfeldt, H. P. (2008). How can primary school students learn self-regulated learning strategies most effectively?: A meta-analysis on self-regulation training programmes. *Educational Research Review, 3*(2), 101–129.

Dignath, C., & Veenman, M. V. J. (2021). The role of direct strategy instruction and indirect activation of self-regulated learning: Evidence from classroom observation studies. *Educational Psychology Review, 33*(2), 489–533. https://doi.org/10.1007/s10648-020-09534-0

Dörrenbächer, L., & Perels, F. (2016). Self-regulated learning profiles in college students: Their relationship to achievement, personality, and the effectiveness of an intervention to foster self-regulated learning. *Learning and Individual Differences, 51*, 229–241. https://doi.org/10.1016/j.lindif.2016.09.015

Du, J., Hew, K. F., & Liu, L. (2023). What can online traces tell us about students' self-regulated learning? A systematic review of online trace data analysis. *Computers & Education, 201*, 1–16. https://doi.org/10.1016/j.compedu.2023.104828

Duffy, M. C., & Azevedo, R. (2015). Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system. *Computers in Human Behavior, 52*, 338–348. https://doi.org/10.1016/j.chb.2015.05.041

Engelmann, K., & Bannert, M. (2021). Analyzing temporal data for understanding the learning process induced by metacognitive prompts. *Learning and Instruction, 72*, 1–11. https://doi.org/10.1016/j.learninstruc.2019.05.002

Espinoza, P., & Genna, G. M. (2021). Hi, I want to talk to you about your progress: A large course intervention for at-risk college students. *Journal of College Student Retention: Research, Theory & Practice, 23*(1), 2–27. https://doi.org/10.1177/1521025118790054

Fan, Y., Lim, L., van der Graaf, J., Kilgour, J., Raković, M., Moore, J., Molenaar, I., Bannert, M., & Gašević, D. (2022). Improving the measurement of self-regulated learning using multi-channel data. *Metacognition and Learning, 17*(3), 1025–1055. https://doi.org/10.1007/s11409-022-09304-z

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist, 34*(10), 906–911. https://doi.org/10.1037/0003-066X.34.10.906

Gašević, D., Mirriahi, N., Dawson, S., & Joksimović, S. (2017). Effects of instructional conditions and experience on the adoption of a learning tool. *Computers in Human Behavior, 67*, 207–220. https://doi.org/10.1016/j.chb.2016.10.026

Geurten, M., Meulemans, T., & Lemaire, P. (2018). From domain-specific to domain-general? The developmental path of metacognition for strategy selection. *Cognitive Development, 48*, 62–81. https://doi.org/10.1016/j.cogdev.2018.08.002

Grammenos, D., & Antona, M. (2018). Future designers: Introducing creativity, design thinking & design to children. *International Journal of Interaction, 16*, 16–24. https://doi.org/10.1016/j.ijcci.2017.10.002

Guo, L. (2022). Using metacognitive prompts to enhance self-regulated learning and learning outcomes: A meta-analysis of experimental studies in computer-based learning environments. *Journal of Computer Assisted Learning, 38*(3), 811–832. https://doi.org/10.1111/jcal.12650

Guo, L. (2023). The effects of the format and frequency of prompts on source evaluation and multiple-text comprehension. *Reading Psychology, 44*(4), 358–387. https://doi.org/10.1080/02702711.2022.2156949

Hayes, A. F. (2018). The PROCESS macro for SPSS and SAS [Computer software] Version 4.3.1. www.afhayes.com.

Heikkinen, S., Saqr, M., Malmberg, J., & Tedre, M. (2023). Supporting self-regulated learning with learning analytics interventions – a systematic literature review. *Education and Information Technologies, 28*(3), 3059–3088. https://doi.org/10.1007/s10639-022-11281-4

Hemmings, B., & Kay, R. (2010). Prior achievement, effort, and mathematics attitude as predictors of current achievement. *Australian Educational Researcher, 37*(2), 41–58. https://doi.org/10.1007/BF03216921

Hew, K. F., Huang, W., Du, J., & Jia, C. (2023). Using chatbots to support student goal setting and social presence in fully online activities: Learner engagement and perceptions. *Journal of Computing in Higher Education, 35*(1), 40–68. https://doi.org/10.1007/s12528-022-09338-x

Hsu, Y.-S., Wang, C.-Y., & Zhang, W.-X. (2017). Supporting technology-enhanced inquiry through metacognitive and cognitive prompts: Sequential analysis of metacognitive actions in response to mixed prompts. *Computers in Human Behavior, 72*, 701–712. https://doi.org/10.1016/j.chb.2016.10.004

Jansen, R. S., van Leeuwen, A., Janssen, J., Jak, S., & Kester, L. (2019). Self-regulated learning partially mediates the effect of self-regulated learning interventions on achievement in higher education: A meta-analysis. *Educational Research Review, 28*, 1–20. https://doi.org/10.1016/j.edurev.2019.100292

Järvelä, S., Järvenoja, H., & Malmberg, J. (2019). Capturing the dynamic and cyclical nature of regulation: Methodological Progress in understanding socially shared regulation in learning. *International Journal of Computer-Supported Collaborative Learning, 14*(4), 425–441. https://doi.org/10.1007/s11412-019-09313-2

Jo, I.-H., Kim, D., & Yoon, M. (2015). Constructing proxy variables to measure adult learners' time management strategies in LMS. *Educational Technology & Society, 18*(3), 214–225. https://www.jstor.org/stable/jeductechsoci.18.3.214.

Johnson, P. O., & Neyman, J. (1936). Tests of certain linear hypotheses and their application to some educational problems. *Statistical Research Memoirs, 1*, 57–93. https://psycnet.apa.org/record/1936-05538-001.

Kanda, T., Hirano, T., Eaton, D., & Ishiguro, H. (2004). Interactive robots as social partners and peer tutors for children: A field trial. *Human-Computer Interaction, 19*(1–2), 61–84. https://doi.org/10.1080/07370024.2004.9667340

Kautzmann, T. R., & Jaques, P. A. (2019). Effects of adaptive training on metacognitive knowledge monitoring ability in computer-based learning. *Computers & Education, 129*, 92–105. https://doi.org/10.1016/j.compedu.2018.10.017

Kim, D., Yoon, M., Jo, I.-H., & Branch, R. M. (2018). Learning analytics to support self-regulated learning in asynchronous online courses: A case study at a women's university in South Korea. *Computers & Education, 127*, 233–251. https://doi.org/10.1016/j.compedu.2018.08.023

Koivuniemi, M., Järvenoja, H., Järvelä, S., & Thomas, V. (2021). An overview of instruments for assessing and supporting elementary school students' self-regulated learning. *Learning: Research and Practice, 7*(2), 109–146. https://doi.org/10.1080/23735082.2020.1859123

Koszalka, T. A., Wilhelm-Chapin, M. K., Hromalik, C. D., Pavlov, Y., & Zhang, L. (2019). Prompting deep learning with interactive technologies: Theoretical perspectives in designing interactive learning resources and environments. In P. Díaz, A. Ioannou, K. K. Bhagat, & J. M. Spector (Eds.), *Smart computing and intelligence. Learning in a digital world: Perspective on interactive technologies for formal and informal education* (pp. 13–36). Springer. https://doi.org/10.1007/978-981-13-8265-9_2.

Kramarski, B., Weiss, I., & Sharon, S. (2013). Generic versus context-specific prompts for supporting self-regulation in mathematical problem solving among students with low or high prior knowledge. *Journal of Cognitive Education and Psychology, 12*(2), 197–214. https://doi.org/10.1891/1945-8959.12.2.197

Lai, C.-L., & Hwang, G.-J. (2016). A self-regulated flipped classroom approach to improving students' learning performance in a mathematics course. *Computers & Education, 100*, 126–140. https://doi.org/10.1016/j.compedu.2016.05.006

Lau, K. L. (2022). Exploring achievement-level differences in implementing self-regulated learning instruction in a classical Chinese reading intervention program. *Frontiers in Education, 7*, 1–12. https://doi.org/10.3389/feduc.2022.948650

Lawson, M. J., Vosniadou, S., van Deur, P., Wyra, M., & Jeffries, D. (2019). Teachers' and students' belief systems about the self-regulation of learning. *Educational Psychology Review, 31*(1), 223–251. https://doi.org/10.1007/s10648-018-9453-7

Lee, D., Watson, S. L., & Watson, W. R. (2019). Systematic literature review on self-regulated learning in massive open online courses. *Australasian Journal of Educational Technology, 35*(1). https://doi.org/10.14742/ajet.3749

Li, T., Fan, Y., Tan, Y., Wang, Y., Singh, S., Li, X., Raković, M., van der Graaf, J., Lim, L., Yang, B., Molenaar, I., Bannert, M., Moore, J., Swiecki, Z., Tsai, Y.-S., Shaffer, D. W., & Gašević, D. (2023). Analytics of self-regulated learning scaffolding: Effects on learning processes. *Frontiers in Psychology, 14*. https://doi.org/10.3389/fpsyg.2023.1206696

Lim, L., Bannert, M., van der Graaf, J., Molenaar, I., Fan, Y., Kilgour, J., Moore, J., & Gašević, D. (2021). Temporal assessment of self-regulated learning by mining students' think-aloud protocols. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.749749

Lim, L., Bannert, M., van der Graaf, J., Singh, S., Fan, Y., Surendrannair, S., Rakovic, M., Molenaar, I., Moore, J., & Gašević, D. (2022). Effects of real-time analytics-based personalized scaffolds on students' self-regulated learning. *Computers in Human Behavior, 139*, 1–18. https://doi.org/10.1016/j.chb.2022.107547

Lodge, J. M., Panadero, E., Broadbent, J., & Barba, P. G. de (2018). Translating learning analytics research for teachers. In J. M. Lodge, J. C. Horvath, & L. Corrin (Eds.), *Learning analytics in the classroom* (pp. 45–55). Routledge.

LogRocket [Computer software]. (2022). *LogRocket*.
Macnamara, B. N., & Burgoyne, A. P. (2022). Do growth mindset interventions impact students' academic achievement? A systematic review and meta-analysis with recommendations for best practices. *Psychological Bulletin*. https://doi.org/10.1037/bul0000352. Advance online publication.
Manlove, S., Lazonder, A. W., & Jong, T. de (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning, 2*(2–3), 141–155. https://doi.org/10.1007/s11409-007-9012-y
McCarthy, K. S., Likens, A. D., Johnson, A. M., Guerrero, T. A., & McNamara, D. S. (2018). Metacognitive overload! Positive and negative effects of metacognitive prompts in an intelligent tutoring system. *International Journal of Artificial Intelligence in Education, 28*(3), 420–438. https://doi.org/10.1007/s40593-018-0164-5
Molenaar, I., Mooij, S. de, Azevedo, R., Bannert, M., Järvelä, S., & Gašević, D. (2023). Measuring self-regulated learning and the role of AI: Five years of research using multimodal multichannel data. *Computers in Human Behavior, 139*, 1–9. https://doi.org/10.1016/j.chb.2022.107540
Molenaar, I., & Roda, C. (2008). Attention management for dynamic and adaptive scaffolding. *Pragmatics and Cognition, 16*(2), 224–271. https://doi.org/10.1075/pc.16.2.04mol
Molenaar, I., van Boxtel, C. A. M., & Sleegers, P. J. C. (2011). Metacognitive scaffolding in an innovative learning arrangement. *Instructional Science, 39*(6), 785–803. https://doi.org/10.1007/s11251-010-9154-1
Montroy, J. J., Bowles, R. P., Skibbe, L. E., McClelland, M. M., & Morrison, F. J. (2016). The development of self-regulation across early childhood. *Developmental Psychology, 52*(11), 1744–1762. https://doi.org/10.1037/dev0000159
Müller, N. M., & Seufert, T. (2018). Effects of self-regulation prompts in hypermedia learning on learning performance and self-efficacy. *Learning and Instruction, 58*, 1–11. https://doi.org/10.1016/j.learninstruc.2018.04.011
Munshi, A., Biswas, G., Baker, R., Ocumpaugh, J., Hutt, S., & Paquette, L. (2023). Analysing adaptive scaffolds that help students develop self-regulated learning behaviours. *Journal of Computer Assisted Learning, 39*(2), 351–368. https://doi.org/10.1111/jcal.12761
Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology, 8*, 1–28. https://doi.org/10.3389/fpsyg.2017.00422. Article 422.
Perry, N., Hutchinson, L. R., Yee, N., & Määttä, E. (2017). Advances in understanding young children's self-regulation of learning. In D. H. Schunk, & J. A. Greene (Eds.), *Educational psychology handbook series. Handbook of self-regulation of learning and performance* (pp. 457–472). Routledge Taylor & Francis Group.
Pieger, E., & Bannert, M. (2018). Differential effects of students' self-directed metacognitive prompts. *Computers in Human Behavior, 86*, 165–173. https://doi.org/10.1016/j.chb.2018.04.022
Pintrich, P. R. (1991). A manual for the use of the motivated strategies for learning questionnaire (MSLQ). https://eric.ed.gov/?id=ed338122.
Plattner, H., Meinel, C., & Weinberg, U. (2009). *Design thinking: Innovation lernen - ideenwelt öffnen.* mi-Wirtschaftsbuch.
Putwain, D. P., & von der Embse, N. P. (2020). Cognitive–behavioral intervention for test anxiety in adolescent students: Do benefits extend to school-related wellbeing and clinical anxiety. *Anxiety, Stress & Coping, 34*(1), 22–36. https://doi.org/10.1080/10615806.2020.1800656
Puustinen, M., & Pulkkinen, L. (2001). Models of self-regulated learning: A review. *Scandinavian Journal of Educational Research, 45*(3), 269–286. https://doi.org/10.1080/00313830120074206
Raleiras, M., Viana, J., & Costa, F. (2020). Adaptive gamification models in higher education: Is there a place for self-regulated learning?. In *EDULEARN proceedings. IATED*. https://doi.org/10.21125/edulearn.2020.1555
Rodrigues, R. L., Ramos, J. L. C., Silva, J. C. S., Dourado, R. A., & Gomes, A. S. (2019). Forecasting students' performance through self-regulated learning behavioral analysis. *International Journal of Distance Education Technologies, 17*(3), 52–74. https://doi.org/10.4018/IJDET.2019070104
Romero, C., & Ventura, S. (2020). Educational data mining and learning analytics: An updated survey. *WIREs Data Mining and Knowledge Discovery, 10*(3). https://doi.org/10.1002/widm.1355
Samuel, T. S., & Warner, J. (2021). "I can math!": Reducing math anxiety and increasing math self-efficacy using a mindfulness and growth mindset-based intervention in first-year students. *Community College Journal of Research and Practice, 45*(3), 205–222. https://doi.org/10.1080/10668926.2019.1666063
Schunk, D. H., & Ertmer, P. A. (2000). Self-regulation and academic learning: Self-efficacy enhancing interventions. In *Handbook of self-regulation* (pp. 631–649). Academic Press.
Schunk, D. H., & Greene, J. A. (2017). Historical, contemporary, and future perspectives on self-regulated learning and performance. In D. H. Schunk, & J. A. Greene (Eds.), *Educational psychology handbook series. Handbook of self-regulation of learning and performance* (2nd ed.). Routledge Taylor & Francis Group.
Seufert, T. (2018). The interplay between self-regulation in learning and cognitive load. *Educational Research Review, 24*, 116–129. https://doi.org/10.1016/j.edurev.2018.03.004
Siadaty, M., Gašević, D., & Hatala, M. (2016a). Measuring the impact of technological scaffolding interventions on micro-level processes of self-regulated workplace learning. *Computers in Human Behavior, 59*, 469–482. https://doi.org/10.1016/j.chb.2016.02.025
Siadaty, M., Gašević, D., & Hatala, M. (2016b). Trace-based micro-analytic measurement of self-regulated learning processes. *Journal of Learning Analytics, 3*(1), 183–214. https://doi.org/10.18608/jla.2016.31.11
Sim, G., & Bond, R. (2021). Eye tracking in child-computer interaction: Challenges and opportunities. *International Journal of Child-Computer Interaction, 30*, Article 100345. https://doi.org/10.1016/j.ijcci.2021.100345
Sitzmann, T., Bell, B. S., Kraiger, K., & Kanar, A. M. (2009). A multilevel analysis of the effect of prompting self-regulation in technology-delivered instruction. *Personnel Psychology, 62*(4), 697–734. https://doi.org/10.1111/j.1744-6570.2009.01155.x
Snow, R. E. (1991). Aptitude-treatment interaction as a framework for research on individual differences in psychotherapy. *Journal of Consulting and Clinical Psychology, 59*(2), 205–216. https://doi.org/10.1037//0022-006x.59.2.205
Sonnenberg, C., & Bannert, M. (2015). Discovering the effects of metacognitive prompts on the sequential structure of SRL-processes using process mining techniques. *Journal of Learning Analytics, 2*(1), 72–100. https://doi.org/10.18608/jla.2015.21.5
Sonnenberg, C., & Bannert, M. (2016). Evaluating the impact of instructional support using data mining and process mining: A micro-level analysis of the effectiveness of metacognitive prompts. *Journal of Educational Data Mining, 8*(2), 51–83. https://eric.ed.gov/?id=ej1125806.
Sonnenberg, C., & Bannert, M. (2019). Using Process Mining to examine the sustainability of instructional support: How stable are the effects of metacognitive prompting on self-regulatory behavior? *Computers in Human Behavior, 96*, 259–272. https://doi.org/10.1016/j.chb.2018.06.003
Spires, H. A., Rowe, J. P., Mott, B. W., & Lester, J. C. (2011). Problem solving and game-based learning: Effects of middle grade students' hypothesis testing strategies on learning outcomes. *Journal of Educational Computing Research, 44*(4), 453–472. https://doi.org/10.2190/EC.44.4.e
Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251–296. https://doi.org/10.1023/A:1022193728205
Tang, L. M., & Kay, J. (2014). Gamification: Metacognitive scaffolding towards long term goals? In M. Kravcik, O. C. Santos, & J. G. Boticario (Chairs) (Eds.), *4th international workshop on personalization approaches in learning environments, aalborg, Denmark*.
Taub, M., Azevedo, R., Bouchet, F., & Khosravifar, B. (2014). Can the use of cognitive and metacognitive self-regulated learning strategies be predicted by learners' levels of prior knowledge in hypermedia-learning environments? *Computers in Human Behavior, 39*, 356–367. https://doi.org/10.1016/j.chb.2014.07.018
Thompson, R. A., & Zamboanga, B. L. (2003). Prior knowledge and its relevance to student achievement in introduction to psychology. *Teaching of Psychology, 30*(2), 96–101. https://doi.org/10.1207/S15328023TOP3002_02
Tsvyatkova, D., & Storni, C. (2019). A review of selected methods, techniques and tools in Child–Computer Interaction (CCI) developed/adapted to support children's involvement in technology development. *International Journal of Child- Computer Interaction, 22*, Article 100148. https://doi.org/10.1016/j.ijcci.2019.100148
van Alten, D. C., Phielix, C., Janssen, J., & Kester, L. (2020). Effects of self-regulated learning prompts in a flipped history classroom. *Computers in Human Behavior, 108*, 1–13. https://doi.org/10.1016/j.chb.2020.106318
van der Stel, M., & Veenman, M. V. J. (2010). Development of metacognitive skillfulness: A longitudinal study. *Learning and Individual Differences, 20*(3), 220–224. https://doi.org/10.1016/j.lindif.2009.11.005
van der Stel, M., & Veenman, M. V. J. (2014). Metacognitive skills and intellectual ability of young adolescents: A longitudinal study from a developmental perspective. *European Journal of Psychology of Education, 29*(1), 117–137. https://doi.org/10.1007/s10212-013-0190-5
van Dijk, A. M., Eysink, T. H., & Jong, T. de (2016). Ability-related differences in performance of an inquiry task: The added value of prompts. *Learning and Individual Differences, 47*, 145–155. https://doi.org/10.1016/j.lindif.2016.01.008
van Halem, N., van Klaveren, C., Drachsler, H., Schmitz, M., & Cornelisz, I. (2020). Tracking patterns in self-regulated learning using students' self-reports and online trace data. *Frontline Learning Research, 8*(3), 140–163. https://eric.ed.gov/?id=ej1260778.
Veenman, M. V. J., & Beishuizen, J. J. (2004). Intellectual and metacognitive skills of novices while studying texts under conditions of text difficulty and time constraint. *Learning and Instruction, 14*(6), 621–640. https://doi.org/10.1016/j.learninstruc.2004.09.004
Veenman, M. V. J., Kok, R., & Blöte, A. W. (2005). The relation between intellectual and metacognitive skills in early adolescence. *Instructional Science, 33*(3), 193–211. https://doi.org/10.1007/s11251-004-2274-8
Veenman, M. V. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences, 15*(2), 159–176. https://doi.org/10.1016/j.lindif.2004.12.001
Vosniadou, S. (2020). Bridging secondary and higher education. The importance of self-regulated learning. *European Review, 28*(1), 94–103. https://doi.org/10.1017/S1062798720000939
Whitebread, D., Bingham, S., Grau, V., Pino Pasternak, D., & Sangster, C. (2007). Development of metacognition and self-regulated learning in young children: Role of collaborative and peer-assisted learning. *Journal of Cognitive Education and Psychology, 6*(3), 433–455. https://doi.org/10.1891/194589507787382043
Whitebread, D., Coltman, P., Pasternak, D. P., Sangster, C., Grau, V., Bingham, S., Almeqdad, Q., & Demetriou, D. (2009). The development of two observational tools for assessing metacognition and self-regulated learning in young children. *Metacognition and Learning, 4*, 63–85. https://doi.org/10.1007/s11409-008-9033-1
Winne, P. H. (2022). Modeling self-regulated learning as learners doing learning science: How trace data and learning analytics help develop skills for self-regulated learning. *Metacognition and Learning, 17*(3), 773–791. https://doi.org/10.1007/s11409-022-09305-y
Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277–304). Routledge.

Wolters, C. A., & Brady, A. C. (2021). College students' time management: A self-regulated learning perspective. *Educational Psychology Review, 33*, 1319–1351.
Wong, J., Baars, M., Davis, D., van der Zee, T., Houben, G.-J., & Paas, F. (2019). Supporting self-regulated learning in online learning environments and MOOCs: A systematic review. *International Journal of Human-Computer Interaction, 35*(4–5), 356–373. https://doi.org/10.1080/10447318.2018.1543084
Wong, J., Baars, M., He, M., Koning, B. B. de, & Paas, F. (2021). Facilitating goal setting and planning to enhance online self-regulation of learning. *Computers in Human Behavior, 124*, 1–15. https://doi.org/10.1016/j.chb.2021.106913
Xu, Z., Zhao, Y., Liew, J., Zhou, X., & Kogut, A. (2023). Synthesizing research evidence on self-regulated learning and academic achievement in online and blended learning environments: A scoping review. *Educational Psychology Review, 39*, 1–17. https://doi.org/10.1016/j.edurev.2023.100510
Yeager, D. S., Hanselman, P., Walton, G. M., Murray, J. S., Crosnoe, R., Muller, C., Tipton, E., Schneider, B., Hulleman, C. S., Hinojosa, C. P., Paunesku, D., Romero, C., Flint, K., Roberts, A., Trott, J., Iachan, R., Buontempo, J., Yang, S. M., Carvalho, C. M., … Dweck, C. S. (2019). A national experiment reveals where a growth mindset improves achievement. *Nature, 573*(7774), 364–369. https://doi.org/10.1038/s41586-019-1466-y
Yeh, Y.-F., Chen, M.-C., Hung, P.-H., & Hwang, G.-J. (2010). Optimal self-explanation prompt design in dynamic multi-representational learning environments. *Computers & Education, 54*(4), 1089–1100. https://doi.org/10.1016/j.compedu.2009.10.013
Yen, M.-H., Chen, S., Wang, C.-Y., Chen, H.-L., Hsu, Y.-S., & Liu, T.-C. (2018). A framework for self-regulated digital learning (SRDL). *Journal of Computer Assisted Learning, 34*(5), 580–589. https://doi.org/10.1111/jcal.12264
Zainuddin, Z., Chu, S. K. W., Shujahat, M., & Perera, C. J. (2020). The impact of gamification on learning and instruction: A systematic review of empirical evidence. *Educational Research Review, 30*. https://doi.org/10.1016/j.edurev.2020.100326
Zheng, L. (2016). The effectiveness of self-regulated learning scaffolds on academic performance in computer-based learning environments: A meta-analysis. *Asia Pacific Education Review, 17*, 187–202. https://doi.org/10.1007/s12564-016-9426-9
Zhang, W. X., Hsu, Y. S., Wang, C. Y., & Ho, Y. T. (2015). Exploring the impacts of cognitive and metacognitive prompting on students' scientific inquiry practices within an e-learning environment. *International Journal of Science Education, 37*(3), 529–553. https://doi.org/10.1080/09500693.2014.996796
Zheng, J., Jiang, N., & Dou, J. (2020). Autonomy support and academic stress: A relationship mediated by self-regulated learning and mastery goal orientation. *New Waves-Educational Research and Development Journal, 23*, 43–63. https://eric.ed.gov/?id=ej1264274.
Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13–39). Academic Press. https://doi/10.1016/B978-012109890-2/50031-7.